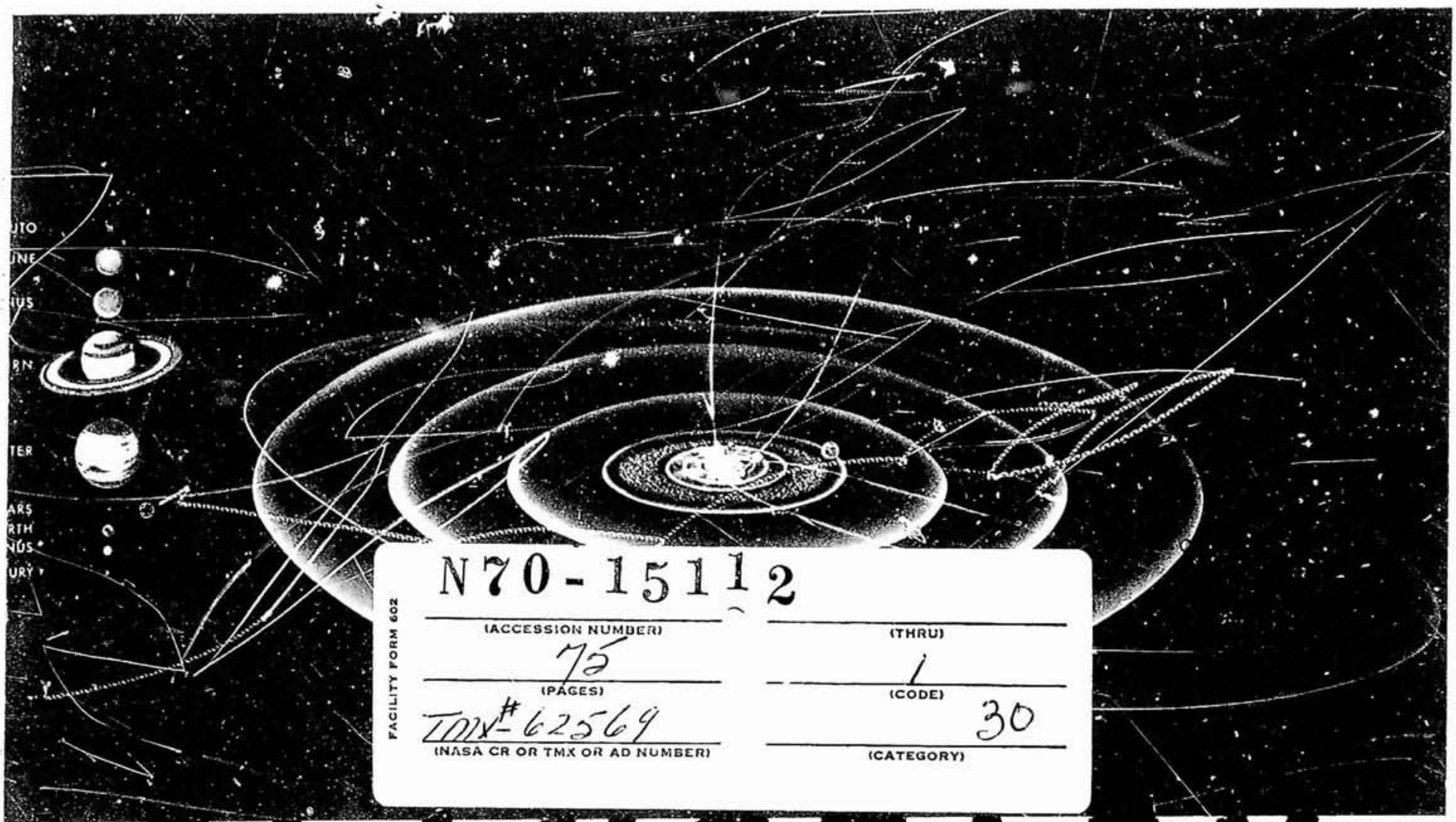

PLANETARY PROGRAM REVIEW

11 JULY 1969

OFFICE OF SPACE SCIENCE AND APPLICATIONS
NASA HEADQUARTERS

NOTE

This review by the Office of Planetary Programs was presented to NASA General Management on 11 July 1969 under the sponsorship of the Office of Space Science and Applications (OSSA). Questions concerning this review and requests for additional copies of this document, should be addressed to the Office of Planetary Programs, Code SL, NASA Headquarters, Washington, D.C. 20546.

PLANETARY PROGRAM REVIEW

11 JULY 1969

PRESENTED BY:

OFFICE OF PLANETARY PROGRAMS;
OFFICE OF SPACE SCIENCE AND APPLICATIONS

GRAPHICS, COMPOSITION AND PUBLICATION BY:

PROGRAM AND SPECIAL REPORTS DIVISION
EXECUTIVE SECRETARIAT

NASA HEADQUARTERS, WASHINGTON, D. C. 20546

Foreword

This report on NASA's Planetary Program provides a baseline review of the objectives, accomplishments, plans, and opportunities associated with this major program of the Office of Space Science and Applications. Planetary Exploration is concerned with the genesis, distribution and composition of planets and their satellites, the comets and asteroids, and other solid materials in the solar system. It includes the search for extraterrestrial life, embraces such lds as geology, geography, petrography, mineralogy, seismology, vulcanology, astronomy, and aeronomy, and extends their scope of interest beyond the earth to include all the condensed material of our solar system. It also includes examination of the interplanetary environment.

The discussion of future programs contained herein addresses itself to the opportunities for space exploration which are within the realm of possibility with current and anticipated technologies. The inclusion of these potential missions and the discussion of their merits does not imply official acceptance or approval by NASA General Management but they are described as illustrations of the range of missions available as options in the next 10 - 15 year time period. Specific program plans to be executed will be the result of careful review and consideration of all program needs within the OSSA, as approved by General Management, and within the framework of program authorizations established by the President and the Congress.

John E. Naugle

Dr. J. E. Naugle
Associate Administrator,
Space Science and Applications

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INTRODUCTION

By: Mr. Donald P. Hearth

Our solar system stretches across a distance of some 8 or 9 billion miles. It includes nine planets with their 32 moons; thousands of asteroids, most of which are located in a belt between the orbits of Mars and Jupiter; and hundreds of comets. Some of the comets may possibly come from outside our solar system.

The planets range in size from Mercury which is a little more than a third of the diameter of Earth, to Jupiter which is over 11 times the diameter of Earth. Thus, Earth, on the scale shown in Figure 1, is a relatively small planet.

The statistics of nine planets and 32 moons may be wrong. Pluto was only discovered in 1930. In addition, the tenth moon of Saturn was discovered in December 1967.

Man has investigated Venus and Mars with spacecraft. In the process, he has examined the 80 million mile portion of the solar system between these two planets. This is a small portion when compared to the 3 to 4 billion mile distance to the planets Neptune and Pluto.

With telescopes man has been able to examine the planets out beyond Mars, although to a limited extent. As we review some of the mysteries of our solar system we will see that most of what we do know has come from man's observations with telescopes.

Fig. 1

Our start in the exploration of our solar system with spacecraft, illustrated in Figure 2, was the Mariner II flight to Venus in 1962 followed by two more Mariners--one to Mars in 1965 and one to Venus in 1967. The Mariner VI and VII spacecraft, launched earlier this year, are rapidly approaching Mars and will be there within 3 weeks. Mariner VI, for example is about 7-1/2 million miles from the planet and closing in rapidly.

During the past 4 years, NASA has placed a series of Pioneer spacecraft into orbit about the Sun to examine the interplanetary medium. The last of the current series of these spacecraft will be launched in August 1969.

Let me define now what we mean by terms like "on-going program," "this year's program," and the "approved program." By these terms we mean the program that President Nixon submitted to the Congress in the Fiscal 1970 budget. In the on-going program, we are broadening our horizons, as shown in Figure 3. We are going out beyond the 80 million mile region discussed earlier, and we're doing more with the nearby planets.

In 1971, for example, we'll be orbiting Mars; thus, extend our observing time of that planet from a matter of minutes, as associated with the flyby, to months and perhaps even longer.

In 1973 we will, for the first time, land on Mars and continue observation from orbit. This will give us our first opportunity to make direct observations on the surface of another planet, and perhaps give us the first clues on the existence of or lack of extraterrestrial life.

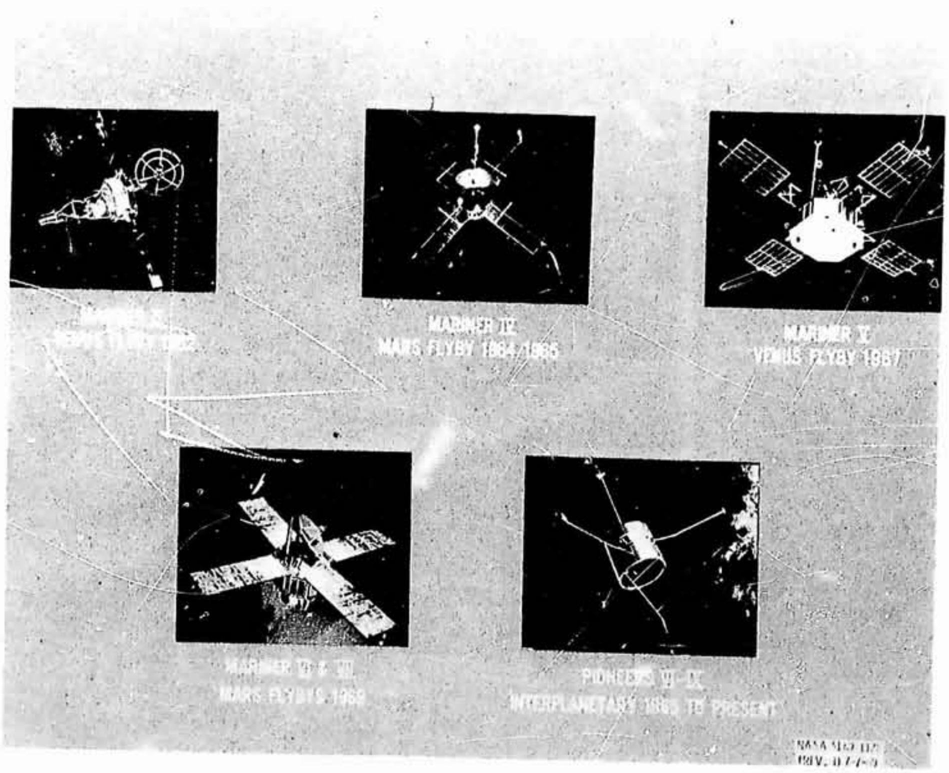


Fig. 2

We're moving outward in the solar system beyond Mars with the Pioneer F & G missions; modifications to the current Pioneer spacecraft used to examine the interplanetary medium. Pioneer F & G will go out to the planet Jupiter, a journey that will take 2 years to complete.

These spacecraft will carry instruments to measure the interplanetary medium. At Jupiter, Pioneer F & G will measure the radiation belts, the magnetic field, and make some measurements of the atmosphere.

We will be searching for an indication of the Helium content on Jupiter. The Helium/Hydrogen ratio is a very important parameter in understanding the planet.

The spacecraft will also carry visual imaging equipment to photograph Jupiter at resolutions considerably better than we get from Earth.

In addition, we're moving in toward the Sun. Our international project with West Germany (Helios) will give us the capability, by 1974, of sending spacecraft inside the orbit of Mercury to within about 30 million miles from the Sun.

In 1973 we also hope to examine, with a Mariner spacecraft, the planet Mercury for the first time. This will be a two-for-one flight in which we will actually view the planet Venus on the way into Mercury.

PLANETARY PROGRAMS SPACECRAFT

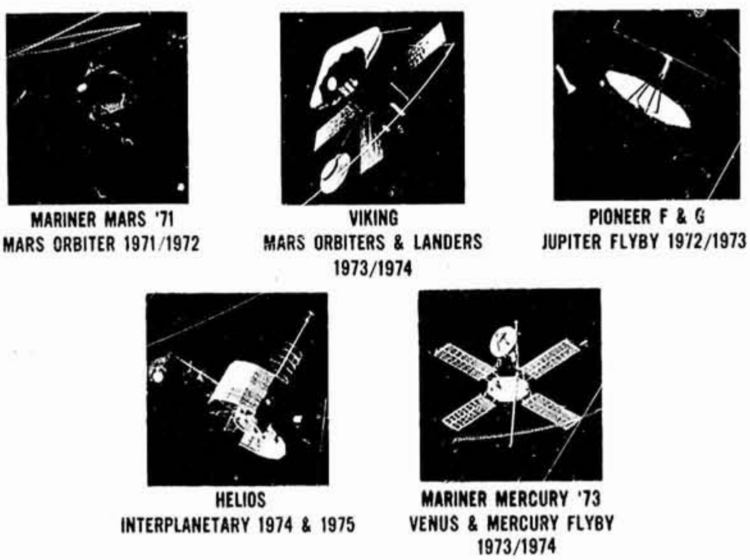


Fig. 3

This, then represents our spacecraft missions in the on-going program. You'll hear more about some of the possibilities for the future later.

Now, this technique; that is, the examination of the planets by spacecraft, is only one means of exploration. Ground-based observations are the other technique.

There are two new telescopes that are coming into operation this year which are being devoted almost entirely to observing the planets (Figure 4): the 88-inch telescope at Hawaii and the 107-inch telescope at the University of Texas. Actually, a number of findings on the planets have been made from telescopes, and these will come out as we move along. One of the more interesting ones, just this year, was from an 82-inch telescope at the University of Texas which found the first concrete evidence of the existence of water vapor in the Martian atmosphere.

This, then is the task we have. I'd like to now review the team that NASA has put together to do this job (Figure 5). I think it's a good team.

Within Headquaters we have some 23 professionals in our office that do the planning and provide overall direction and guidance to the program.

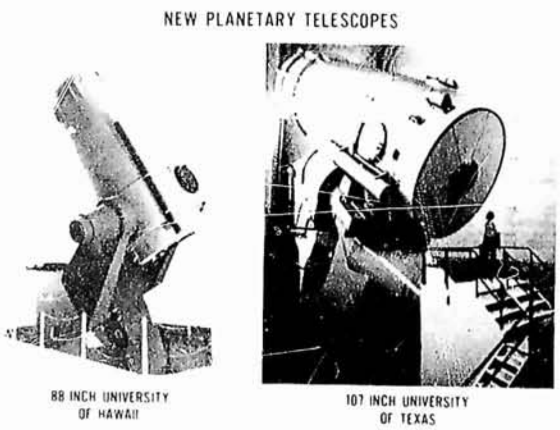


Fig. 4

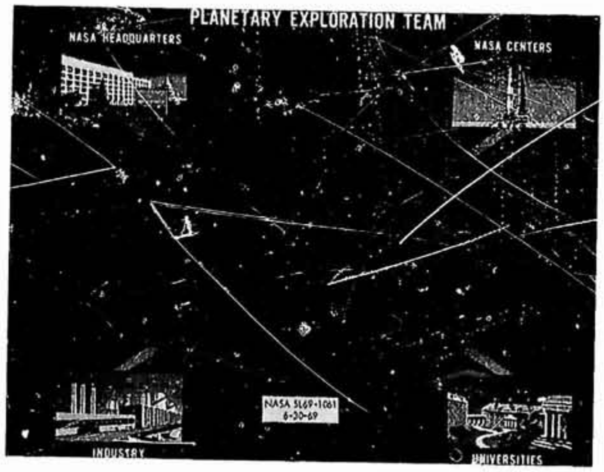


Fig. 5

We depend very heavily on the management and technical capabilities of the NASA field centers (Figure 6). The Jet Propulsion Laboratory has been actively engaged in the planetary program dating back to Mariner II, and including the current Mariners that are on their way to Mars. I would expect that JPL will continue to play a major role in the future.

The Ames Research Center has been responsible for the Pioneer Project since about 1962 or 1963 and will be responsible for the modifications to the Pioneer for the Jupiter missions.

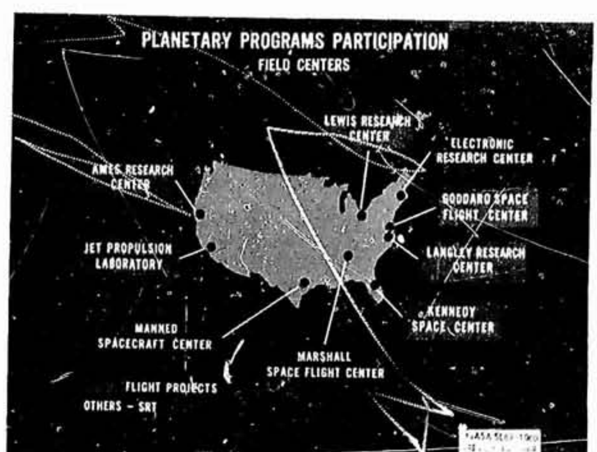


Fig. 6

The Langley Research Center, which did an excellent job on the Lunar Orbiter Project, is responsible for Viking, the orbiter/lander combination to Mars in 1973. They will also have a major role in the future.

Our international project, Helios, is the responsibility of Goddard, which is also responsible for the Delta launch vehicle with which we have been launching our Pioneers. Our larger launch vehicles, the Atlas Centaur and the Titan family, are the responsibility of the Lewis Research Center in Cleveland. All of our planetary launches are from the Cape.

This, then, represents the six NASA centers involved in our flight projects. We are also assisted in the Supporting Research and Technology Program by three other centers: the Electronics Research Center, the Marshall Space Flight Center, and the Manned Spacecraft Center.

This is the NASA team involved in the program. NASA depends, of course, very heavily upon two other groups in the country (Figure 7).

Most of our scientific investigators come from the universities. There are 53 colleges and universities involved in our program at various geographical locations across the United States.

Most of the hardware is provided by industry, and there are literally hundreds of organizations involved. There are some 21 industrial organizations involved to a major extent--again, spread geographically across the United States.

Today you are hearing from four members of this team; we are only spokesmen for this team.

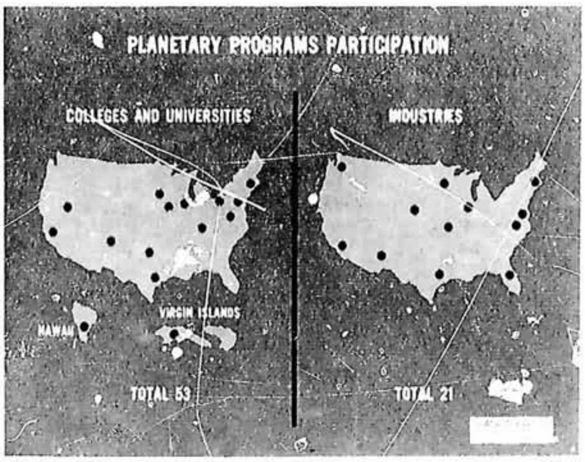


Fig. 7

Before Dr. Rea reviews the scientific aspects of the program, I'd like to say a few words on the values of exploring our solar system.

The opportunity for scientific discovery---answering important questions such as does life exist elsewhere in our solar system, or answering the question as to why did life develop only on the Earth. The application of this scientific knowledge to a better understanding of our own planet, the Earth, is also important. But there are two other values which we sometimes fail to mention. They're what I call exploration and technology.

Picture the sense of exploring this vast exapnse, of going out to planets such as Neptune and Pluto 3 billion and 4 billion miles in space, and returning photographs of these planets back to Earth. It is very challenging and very exciting, and is the sort of thing that this nation can be proud of. If one looks back through history he will find that countries, and indeed whole societies have wanted to explore the unknown and achieve the difficult, providing society with an opportunity to look upward. In its small way, I think planetary exploration fills that desire.

By its very nature, these missions are very difficult and force the growth of technology. Again, history has clearly shown the need to provide stimulants to technology if we are to make progress.

Why explore the solar system? There are three reasons--science, exploration, and technology.

Dr. Rea will not discuss the goals and objectives of our program and what I call the mysteries of our solar system.

GOALS AND OBJECTIVES

By: Dr. Donald G. Rea

Our Planetary Program is structured around three goals, outlined in Figure 1.

Number one is understanding the origin and evolution of the solar system, how the system came into being, how it has evolved in the course of billions of years.

The second one is to understand the origin and evolution of life; one of our most significant areas of inquiry at the present time.

The third one is getting a better understanding of terrestrial phenomena by doing comparative studies on the other planets.

Understanding our own atmosphere, interior, and surface is very difficult. We cannot do experiments on these as we can on lab problems. So, being able to go to another planet where the boundary conditions are different will give us a better understanding of the complex ways in which the physics and chemistry of our planet have operated.

These are the three goals that our program is structured about. I will take them one at a time--starting off with the origin and evolution of our solar system (Figure 2).

Here are two hypotheses for this origin and evolution; the solar nebula having the sun already formed. We don't know whether it developed in the nebula itself or whether our sun picked up the nebula in a collision. So there's a stage omitted from the top of this chart.

There are two ways in which this nebula has evolved. In one, condensations form protoplanets which evolve rather smoothly to our present system.

The second one involves condensations throughout the nebula forming small particles or planetesimals, which then proceed to interact by collision, by disintegration, accretion, and rearrangement, proceeding on to the present arrangement.

From here there's another stage. Each of these bodies can undergo further processes which are independent and have nothing to do with interaction with the other bodies. In the evolution of earth, the differentiation of the interior is an example of this process.

I'm going to go through each of the planets with brief comments on the salient points of our knowledge at the present time, and on the questions we want to have answered in relation to these two hypotheses.

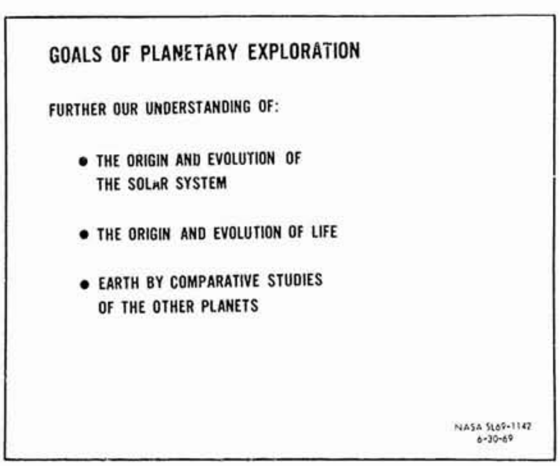


Fig. 1

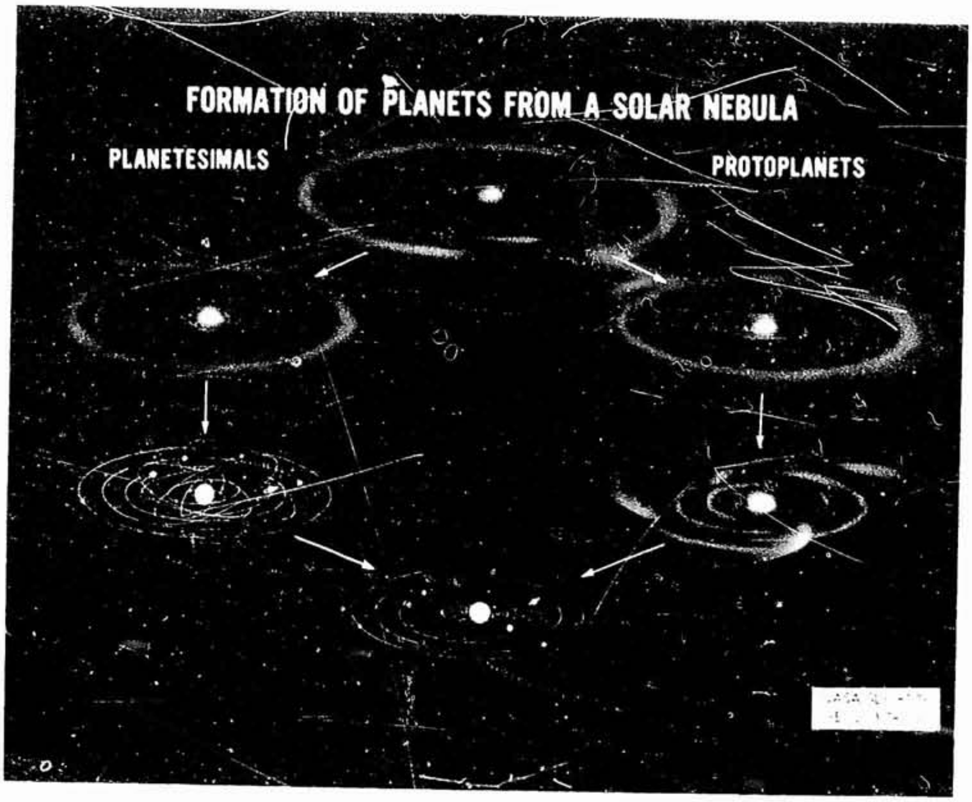


Fig. 2

I want to emphasize that we are not merely acquiring data for the sake of acquiring data. Rather, we want to understand the process by which this has all come to pass.

The first planet, moving out from the Sun, is Mercury, shown in Figure 3. In size it's somewhat larger than the moon. Its density is very high. We believe this is either due to a high concentration of iron, or due to loss of volatiles, relative to Earth.

So it seems as though either its original formation was different, or else in the evolutionary process it has differed from earth.

The spin, that is the rotation about the rotational axis, and the motion around the sun, have an unusual coupling that Bill Brunk will comment on in some detail later. We believe at the present time that, in order for this coupling to have developed, there has to be a liquid core inside the planet.

So far no atmosphere has been detected. The upper limit is--depending upon whom you believe--either 1/1000th or 1/100,000ths that of earth.

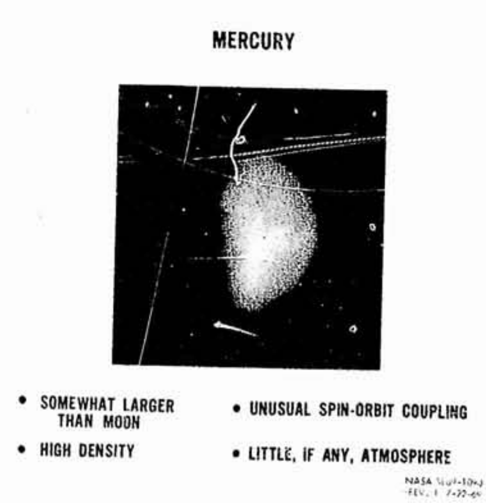


Fig. 3

The next planet out is Venus (Figure 4). In many ways it's similar to Earth. It's roughly the same size--a little bit smaller--the mass a little bit less, the density is a bit less. But basically it's similar.

However, there are some rather gross differences when we start looking at details. It's the only planet in the solar system which has a retrograde rotation. That is, looking down from the North Pole--instead of rotating counter-clockwise, it rotates clockwise. Bill Brunk will comment on this unusual coupling that we have no really rigorous theory for at the present time. There are some ideas, but our understanding is in the preliminary stages.

The atmosphere and the atmospheric pressure at the surface are quite different from earth. Our current beliefs are there's a surface pressure roughly 100 times ours. And the temperature is up around 900° Fahrenheit. So while Venus is in many ways very similar to Earth, these wide differences exist. The atmosphere is around 90 - 95 percent carbon dioxide. Some minor constituents have been detected. Water is one, carbon monoxide is a second, and the acids, hydrogen chloride and hydrogen fluoride are others. These acids are in such concentrations that if the clouds are at any point liquid water, they would not be merely water--they would be strong acid. So, it's an awesome place.

These pictures are in the ultraviolet. If I had pictures in the visible you would see no structures at all. These features are detected only in the ultraviolet.

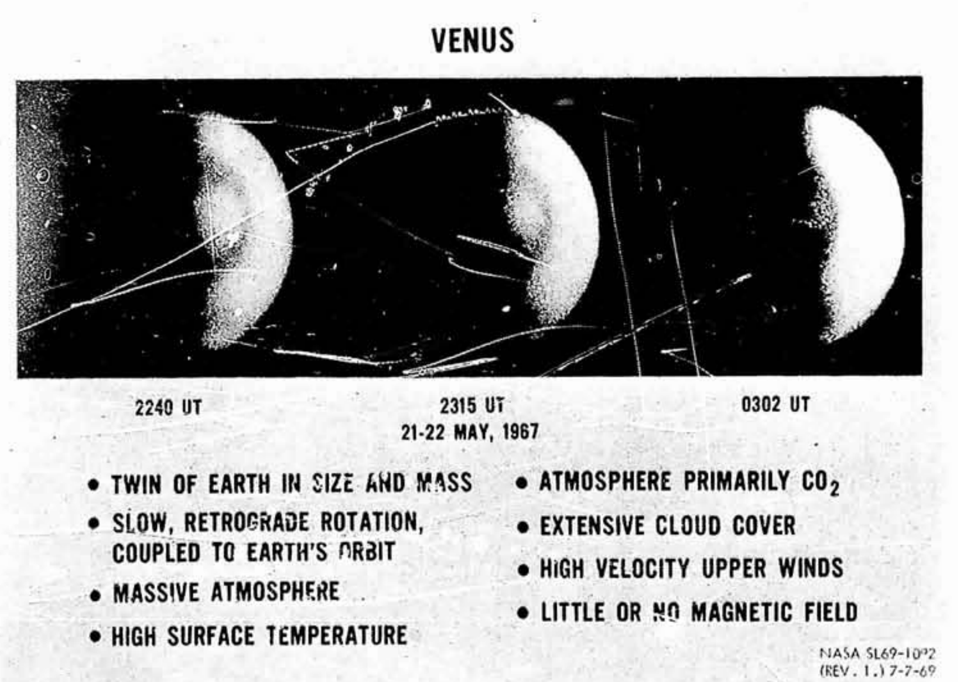


Fig. 4

This is an unusual one which is circular. You'll notice it's moving across the planet in this sequence. The velocity is some 250 miles an hour. Structures have been observed in other ultraviolet pictures, again with the same speed. To my knowledge, there is no theory advanced for this phenomenon at this time. This is a rather peculiar oddity on Venus, one of many.

The Mariner II and V spacecraft did not detect any magnetic field. The upper limit is roughly 1/1000 of ours.

So, while Venus seems to be similar to Earth, it clearly has noted differences. How these are related to the hypotheses of the origin and evolution of the solar system is one of our major problems.

Now we come to the planet which has received the greatest portion of our attention so far, and that is Mars (Figure 5).

The day is half an hour longer than ours. The rotation axis is tilted about 24° to the orbit so that there are seasons very similar to ours; but since the year is 687 days long, the seasons are close to being double the length of ours.

The atmospheric pressure at the surface is about 10 millibars, which is 1/100th the pressure of Earth. This atmosphere, like Venus, appears to be largely carbon dioxide. Water and carbon monoxide have also been detected but in small amounts.

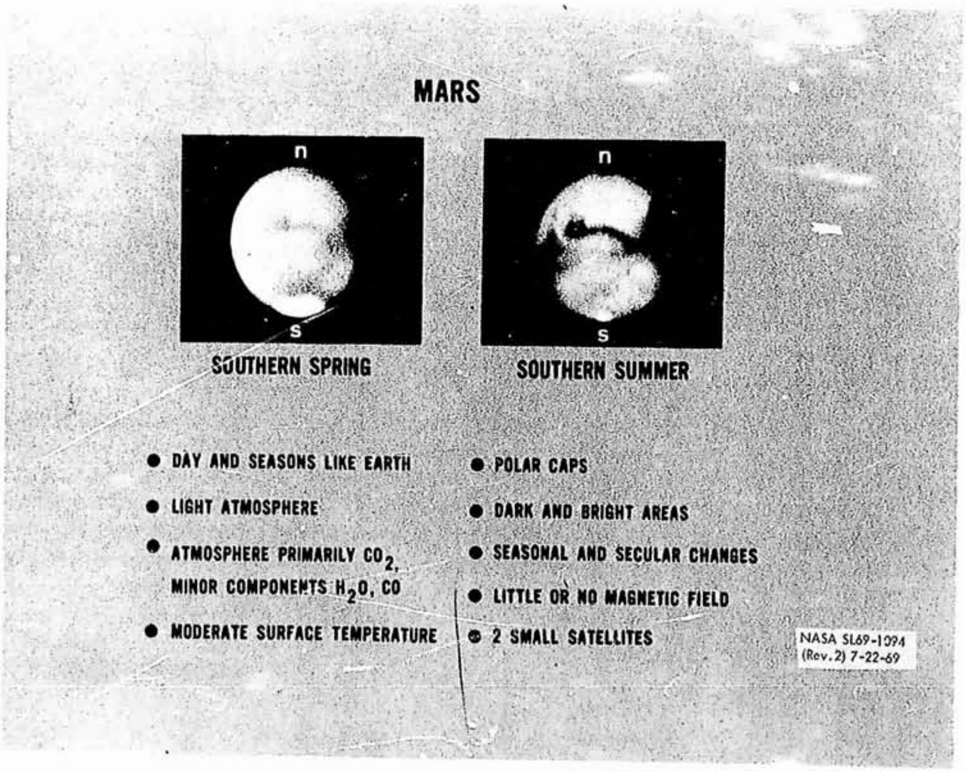


Fig. 5

The surface temperature is relatively moderate at the equator, it gets up to around 70° or 80° Fahrenheit. However, due to the thin atmosphere and the surface properties, there is a large diurnal range--about 200° Fahrenheit at the equator.

The white areas at the poles are called polar caps. At one time we thought they were water ice-hoar frost, but now the best theory is that they are frozen carbon dioxide--dry ice.

There are bright and dark areas. The dark areas do not keep their configurations the same or their darkness. Here you see in southern spring a rather large polar cap, and the dark areas are relatively muted. As the cap recedes, the dark areas near it begin to get darker; and as it further recedes, this darkening moves across the planet in what is called a darkening wave.

One original explanation of the darkening wave is that it is the visual appearance of a growth of vegetation. The cap releases water as it recedes, the organisms in the soil respond to this water, they grow, proliferate, and the surface darkens.

However, there are other explanations which are not biological, and I think at the present time, the nonbiological ones are favored.

The dark areas not only undergo seasonal changes but also secular changes. In particular, there are two canals which we cannot see in this view called Thoth-Nepenthes and which have shown a great change in the last few years.

Some of these surface features have been photographed by the Mariner IV spacecraft. Figure 6 shows four pictures which were obtained. The first one is an historic one. It's the first spacecraft picture of a planet and shows the limb.

What I think is one of the most exciting pictures is the frame numbered 11, showing numerous craters as the others do, but also this very large one. This sequence of pictures has picked up something like 300 craters, ranging from 3 kilometers up to 180 kilometers in diameter.

We expect that Mariners VI and VII will work perfectly; and as Bob Kraemer will say later, they will give us a large number of pictures, which will be of much higher quality than we have now.

Mariner IV did not detect a magnetic field, with an upper limit about 1/1000 earth's.

Two small satellites are known--Phobos and Deimos. Phobos rotates with a period around Mars of 8 hours--the only planet in the solar system to have an orbital period which is shorter than the rotational period of its planet.

At one time it was believed that Phobos was accelerating--moving into the planet. This was not possible based on calculations assuming a solid satellite; it was supposed then by Shklovsky that the satellite was hollow. Well, the natural step then was that it had to be put into orbit by intelligent Martians. But this has not stood the test of time; and in fact, the observations themselves are questioned right now. So we have no reason to believe that we have a competing space program on Mars.

You have seen that Mars has many characteristics different from those of Mercury and Venus. So its place in the evolutionary scheme seems to be different. We hope that by studying the planet we can get a better understanding of the factors responsible.

MARINER IV- MARS PHOTOS

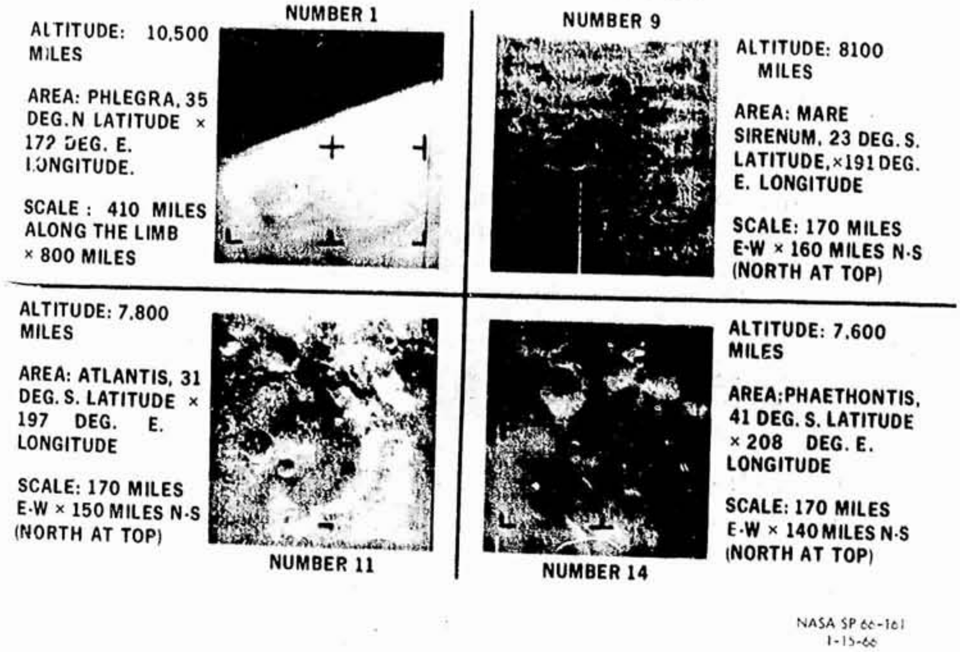


Fig. 6

Going further out we have the most massive planet in the solar system, Jupiter (Figure 7). It is 318 times the mass of Earth but has a very low density. It rotates very rapidly, the period being somewhat less than 10 hours.

Its radius is some 11 times that of earth. It's striking to have this huge body rotating with a period which is less than half that of earth.

The atmospheric constituents that have so far been detected are hydrogen, with minor amounts of methane and ammonia. Helium is inferred. The helium/hydrogen ratio is a very important parameter in studies and calculations on the structure of the planet and on its evolution. One of the experiments on Pioneers F and G is aimed at getting a better feeling for this ratio.

When you look at the planet on a somewhat larger scale (Figure 8), you get a better appreciation its structure.

This is a shadow of one of the Galilean satellites. The planet has bands going across it, although the structure does change with time. The famous Red Spot was detected a little over 300 years ago, and it seems to float on the planet. It doesn't change in latitude, but it floats in longitude. In the course of the last 200 years, it has revolved around the planet 3 times, and now it's winding back again. It's almost back to where it was about 200 years ago.

There are theories for it but none without some rather serious objections.

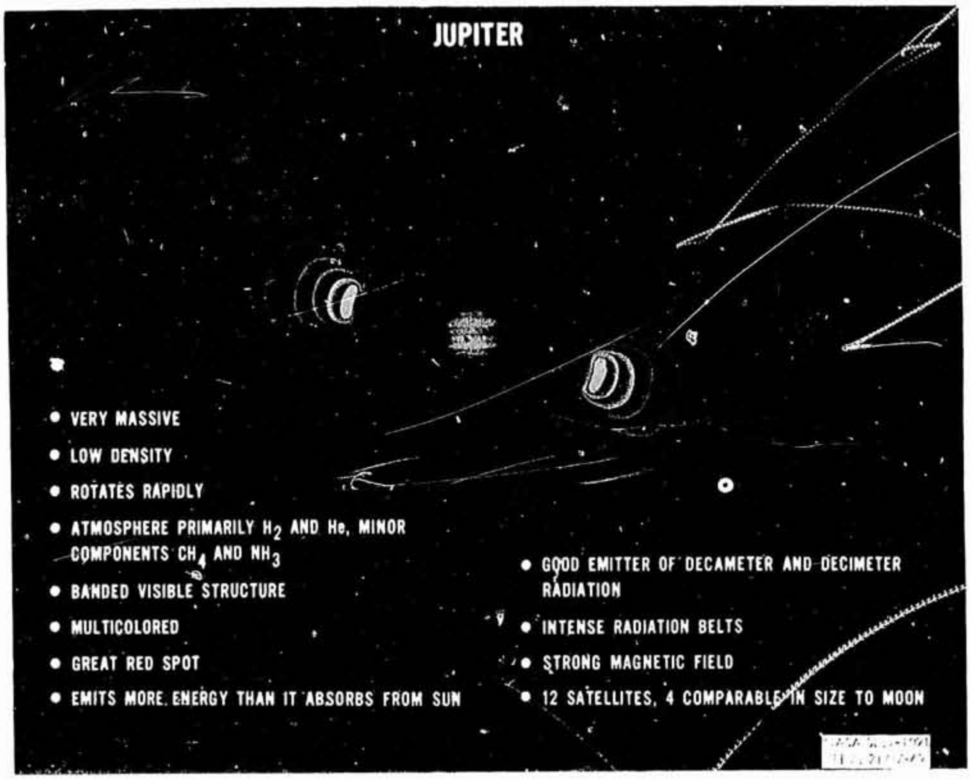

JUPITER
• VERY MASSIVE
• LOW DENSITY
• ROTATES RAPIDLY
• ATMOSPHERE PRIMARILY H_2 AND He, MINOR COMPONENTS CH_4 AND NH_3
• BANDED VISIBLE STRUCTURE
• MULTICOLORED
• GREAT RED SPOT
• EMITS MORE ENERGY THAN IT ABSORBS FROM SUN
• GOOD EMITTER OF DECAMETER AND DECIMETER RADIATION
• INTENSE RADIATION BELTS
• STRONG MAGNETIC FIELD
• 12 SATELLITES, 4 COMPARABLE IN SIZE TO MOON

Fig. 7

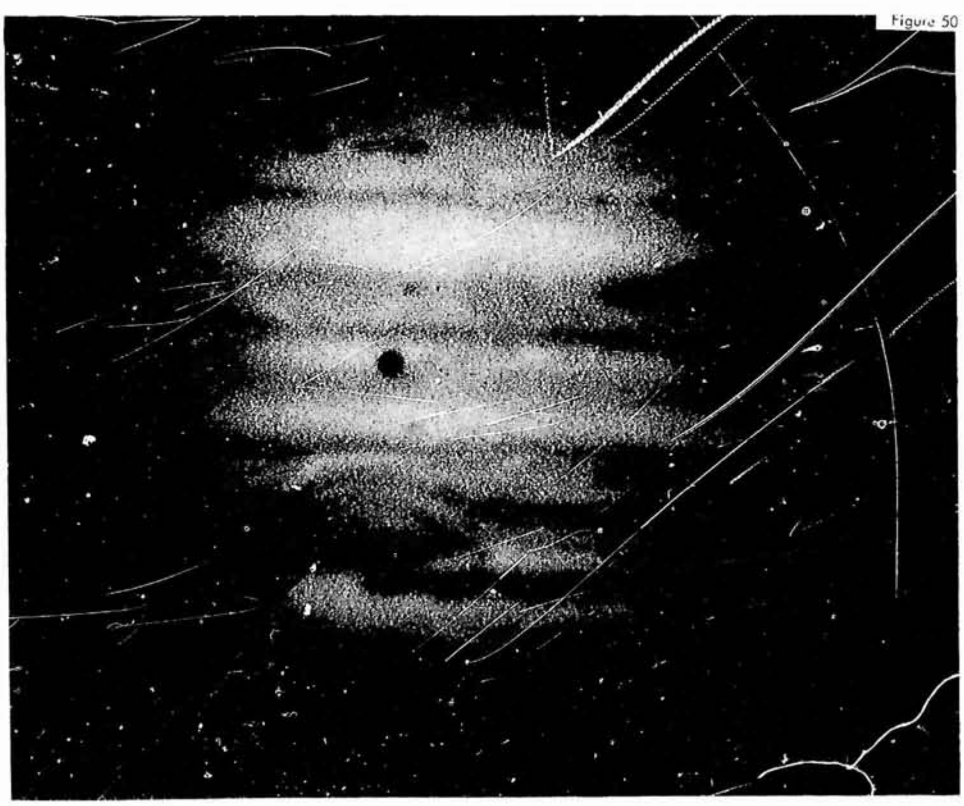


Figure 50

Fig. 8

To give you an idea for the size, Earth is only 1/3 of the length of the Red Spot. You can see that Earth is rather a trivial object in terms of size when you're talking about something like Jupiter.

The pastel colors are also peculiar to Jupiter, and I'll comment briefly on that later. One proposal is that there are complex organic molecules in the upper atmosphere.

Jupiter is the first planet that was observed to emit more energy than it absorbs. Our measurements currently indicate that it emits roughly twice as much energy as it absorbs; one hypothesis for this is that it is due to contraction; the planet is still contracting, the gravitational energy being released accounting for this excess energy.

In 1955 there was an accidental discovery that Jupiter is a strong emitter of bursts of decameter radiation, radiation with wavelengths some tens of meters. It was a purely accidental discovery, and yet it turned out to be very important. Since then, shorter wavelength radiation has also been detected.

The mechanisms for producing this radiation are believed to involve energetic electrons in a radiation belt which is somewhat analogous to our Van Allen belt. The fluxes, according to at least a model, are somewhat larger than those of earth, but the magnetic fields are much larger. Field strengths of 10 to 50 gauss are estimated at the surface, about 20 to 100 times our own surface field.

Jupiter has twelve satellites. In size, two of these are comparable to the Moon and two to Mercury. So it has its own satellite system, very reminiscent of the satellite system that the Sun has.

The satellite, Io, which is the inner one of the four Galilean satellites, modulates the radiation, which comes in bursts. The mechanism of this modulation is not understood, or how Io would interact with the trapped radiation and inevitably dump the particles out. We hope that Pioneers F and G will provide some insight, but I am not sure if they will. I expect that we're not going to get a really good understanding of this until we get a Jupiter orbiter.

But it's interesting that this is the only one of the Galilean satellites that appears to have this effect, despite the fact that at least one or two of the others are believed to be within the belts. So there's something strange about Io.

Also, there's some evidence that Io may have an atmosphere. As a matter of fact, some theories of the evolution of the solar system can be investigated by looking at the satellite system of an individual planet.

Jupiter is thus a very unusual object. Because of its low density and very high hydrogen content, we believe that it may represent the primordial nebular material; and that after the condensation process, the body that was formed has not lost any of its gas during its further evolutionary stages.

This may then provide us with an opportunity to find out what the nebula was like at the time the planets were formed.

Jupiter is only one of the four so-called Jovian planets (Figure 9). Really they should be broken down into two classes. One is Jupiter and Saturn. They're similar in size, the uncompressed densities are roughly the same, their compositions are similar, and each has an energy imbalance.

A major difference, however, is that Saturn has these rings. We don't know at the present time what the composition of the rings is. Various ideas have been put forward--ice, dust covered with ice, and most recently polymerized formaldehyde.

The rings are very thin. When one sees them edge on, there's practically nothing to be seen. The upper limit of the thickness is around a mile or two, but they may be much thinner than that.

The other two of the Jovian planets are Uranus and Neptune. These are over-exposed pictures to bring out some of the satellites; but even if they were not, we would not see structure. They'd still be too far away, and it would have to be a very large-scale structure to be detected.

The densities are significantly higher than Jupiter and Saturn, so evidently they've lost a lot of hydrogen, or they didn't have the hydrogen when they originally condensed.

Uranus is unique in the solar system in that its rotational axis is tilted 98° to its orbital plane, whereas the maximum amount of tilt of any other planet is around 24°. This unusual effect implies some extraordinary event in its origin or evolution.

Neptune is very similar to Uranus. It has two satellites--one, Triton, which is very large and a smaller one, Nereid.

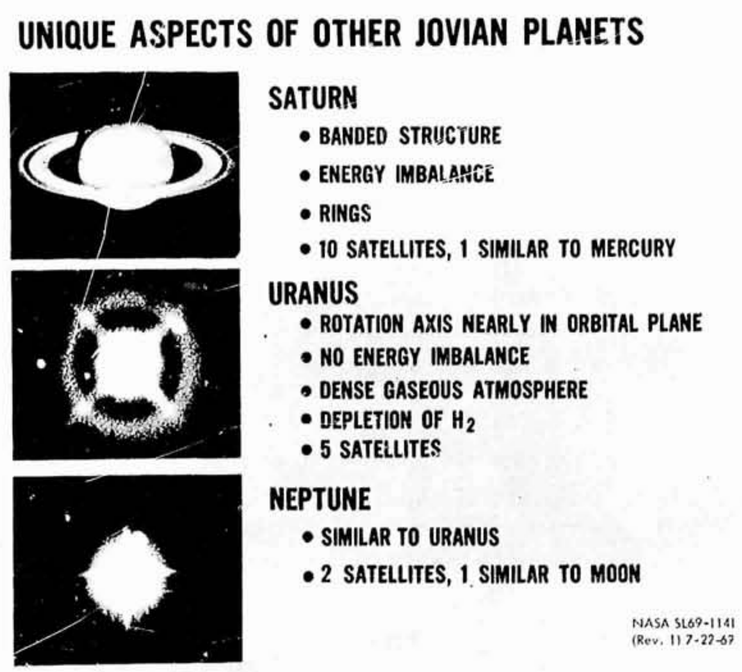


Fig. 9

Progressing beyond the Jovian planets, we come to the last one that we know of at the present time--Pluto (Figure 10).

It is shown in a star field and is, in even this narrow field picture, dimmer than many stars. Because of its faintness, we know very little about it. Its size is uncertain, but appears to be somewhat smaller than Mars.

The mass and density are currently debatable. Present estimates give a rather high density, but there are major uncertainties in the analysis. We hope that analyses underway on the motions of the outer planets will provide a more reliable mass and density.

Its orbit is highly inclined to the ecliptic and is also highly eccentric. Consequently it is conjectured that at one time Pluto was a satellite of Neptune. This would bear on rearrangement mechanisms active during the evolution of the solar system.

We know very little about Pluto. In exploring it we want to make basic measurements, things we know reasonably well for the other planets. We hope to make this class of measurements together with more sophisticated observations in the late 70's.

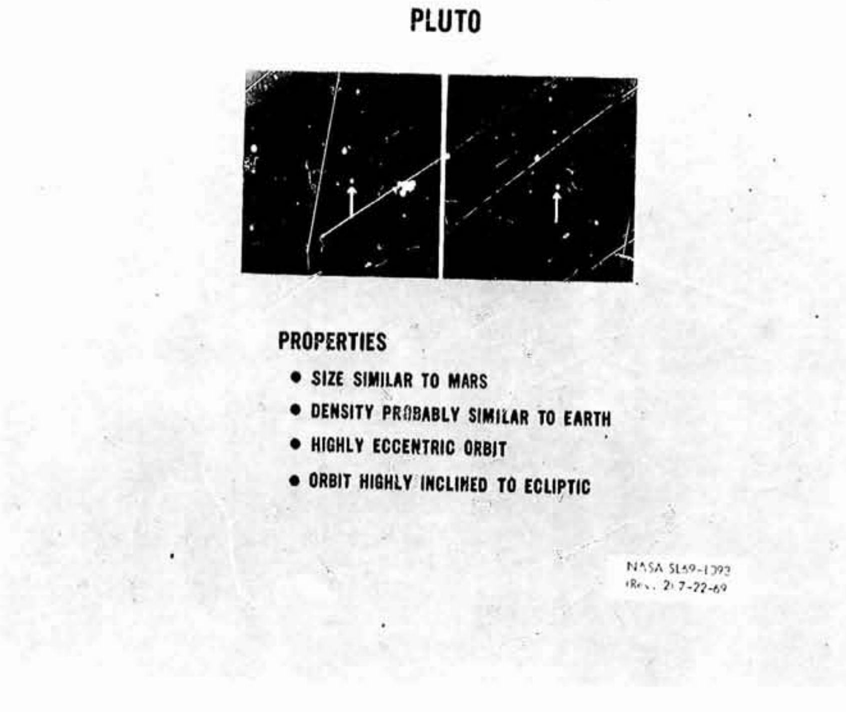


Fig. 10

Now we come to the asteroids (Figure 11). There are some 1600 asteroids which have been detected, the vast majority in a belt between Mars and Jupiter. Some 20 have been detected which have diameters greater than 100 miles, the figure shows four of these.

There is at least one theory on current processes in the belt, which involves mechanisms very similar to mechanisms suggested for the very early condensation in the solar nebula. So an understanding of those mechanisms should give us a better feeling for the early solar system.

Furthermore, it appears that many of our meteorites come from the asteroid belt, and that they are asteroid fragments.

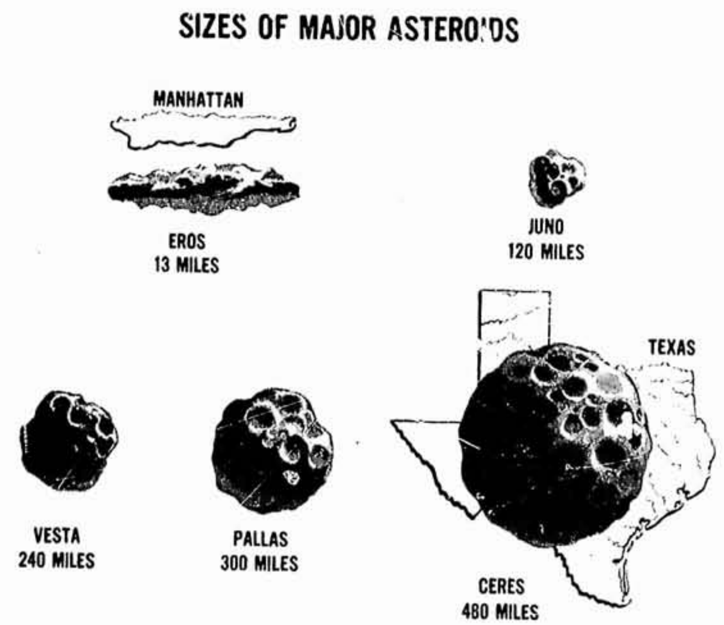


Fig. 11

Finally, we come to the comets. Figure 12 shows Halley's Comet which has a period of 76 years, coming back next in '86. We don't know whether all of the comets belong to our solar system or not. If they are not part of our solar system, they will provide us with an unusual opportunity to analyze matter from outside of our own environment.

This is a brief rundown of our first planetary exploration goal.

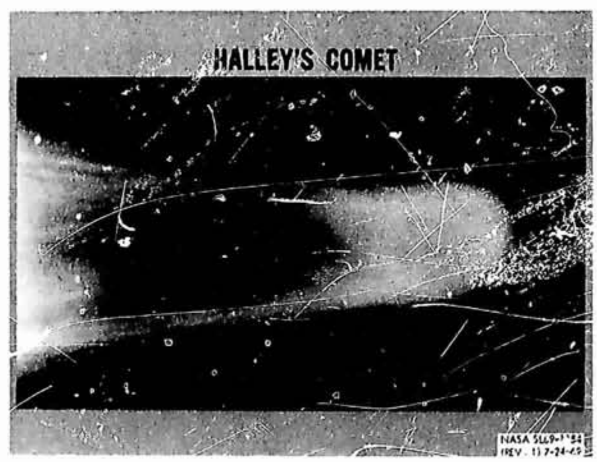


Fig. 12

Regarding the second one, getting a better understanding of the origin and evolution of life (Figure 13), the item which immediately comes to mind is, of course, Martian exploration.

I will not dwell on this subject here, but will restrict myself to two other aspects which may not be quite so obvious.

It is believed that the evolution of the earth and the evolution of life proceeded in parallel. We start off with earth with no atmosphere. Extensive outgassing produces a reducing atmosphere containing water, methane, and ammonia. There are bodies of liquid water--oceans, ponds, etc.

Energy enters the atmosphere via sources such as lightning discharges, volcanoes, and ultraviolet radiation. Complex organic molecules are formed, they dissolve in the ponds, and then life spontaneously arises.

The initial life forms cannot be in the upper part of the water because the ultraviolet radiation is lethal. But the radiation decomposes the water vapor, hydrogen is lost by escape, and the oxygen so formed then produces ozone. The ozone forms a UV protective layer over the water so that the biota can come close to the surface. Then photosynthesis is initiated and large amounts of oxygen are produced. This in turn produces a very extensive ozone layer, and life can emerge from the water and exist on land and in the air.

The point I want to make is that the origin and evolution of life are intimately tied to the evolution of earth itself. However, we have many open questions in this evolutionary scheme of earth.

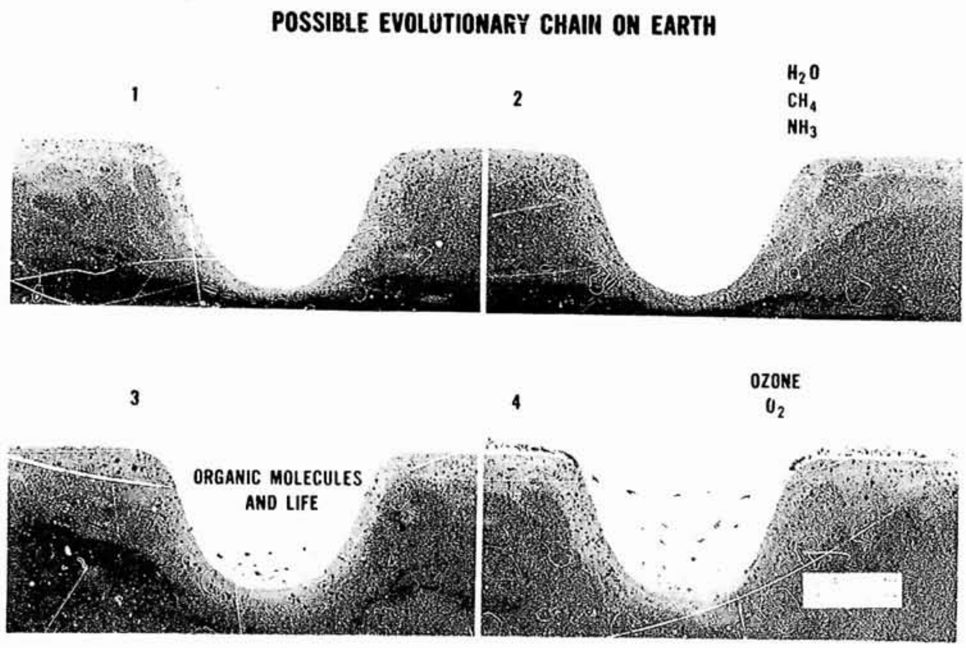


Fig. 13

We may be able to tie this down better by comparative studies of the other terrestrial planets (Figure 14). Mercury has no atmosphere--at least we haven't detected one so far, but it evidently has a core. This suggests that Mercury is in a late stage of evolution, that it has produced a atmosphere which has been subsequently lost.

Venus, on the other hand, has an atmosphere that is very massive and is largely carbon dioxide. The carbon dioxide is roughly the same amount we have on earth, if we take into account the CO_2 which is combined in carbonates. We're not sure just how this fits into the scheme of things. It may be that it's gone through the stage that earth is in, or it may be that the water has never come out, and that it's trapped below the surface.

We have a fair knowledge of the present atmospheric conditions on Mars. Like Venus, it has a lot of CO_2. It's a major question as to why it has this amount of carbon dioxide, having such a light atmosphere. I won't go into the arguments, but I think it's the consensus right now that Mars is in an early stage of evolution. At any rate we believe that a comparative study of all of the terrestrial planets will give us a better understanding of the evolutionary process on earth. In turn, this will give us a better understanding for the origin and evolution of life on earth.

The second item I want to comment on is the step from a reducing gas mixture to complex organic molecules of biological importance (Figure 15). If you take hydrogen, ammonia, methane, water, and put energy into the mixture (e.g. by a spark discharge) complex molecules result. These include glycine, one of the alpha amino acids from which proteins are formed, and adenine and cytosine, which are essential ingredients in our genetic material. These and other important biochemicals have been produced in laboratory reactions.

On Jupiter we believe that the conditions at the present time are such that these same reactions may be occurring. I have already mentioned that the colors of Jupiter may be due to organic molecules formed in the upper atmosphere.

These particular ones happen not to be colored; but Mr. Ponnamperuma at the Ames Research Center has taken mixtures like this, passed a discharge through, condensed the molecules produced, and obtained a red material which looks very similar to some of the colors we see on Jupiter.

PRESENT ATMOSPHERES OF TERRESTRIAL PLANETS

	PRESSURE (Atm)	MAJOR COMPONENTS	H_2O CONTENT
MERCURY	~0	–	–
VENUS	100	CO_2	LOW
EARTH	1	N_2, O_2	HIGH
MARS	0.01	CO_2	LOW

NASA SL69-1143
6-30-69

Fig. 14

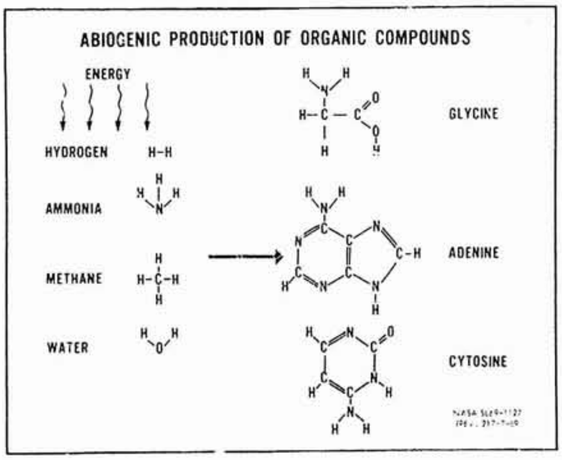


Fig. 15

So it is suggested that reactions like this may be occurring on Jupiter. We'd like to get there and try to see if this is going on in order to bridge the gap between the laboratory and nature.

Finally, our third goal is getting a better feeling for earth by looking at the other planets. Here I will comment on two aspects. One is the atmosphere of earth, and the second is the interior of earth.

Figure 16 illustrates plots of pressure and temperature versus altitude for Venus. The solid curve is from Mariner V and the dashed one from Venera 4.

The horizontal line near 6050 km is the radius which was established initially by radar by itself and finally by the combination of radar with measurements on Mariner V. It was originally believed by the Russians that Venera 4 had landed so that the radius would have to be about 6075 km. This was questioned by our scientists because it contradicted a great deal of our prior understanding.

This disagreement was recently resolved when the Russians, in reporting on their Veneras 5 and 6, stated that they now agree that not only Veneras 5 and 6, but also Venera 4, did not reach the surface.

The radar results from Veneras 5 and 6 have been interpreted to indicate an elevation difference of 10 miles. This is in contradiction with our radar which shows no structures, no elevations greater than a mile. Furthermore, the surface is very hot and it has been estimated that the feature would have to be stainless steel in order to be able to retain its existence.

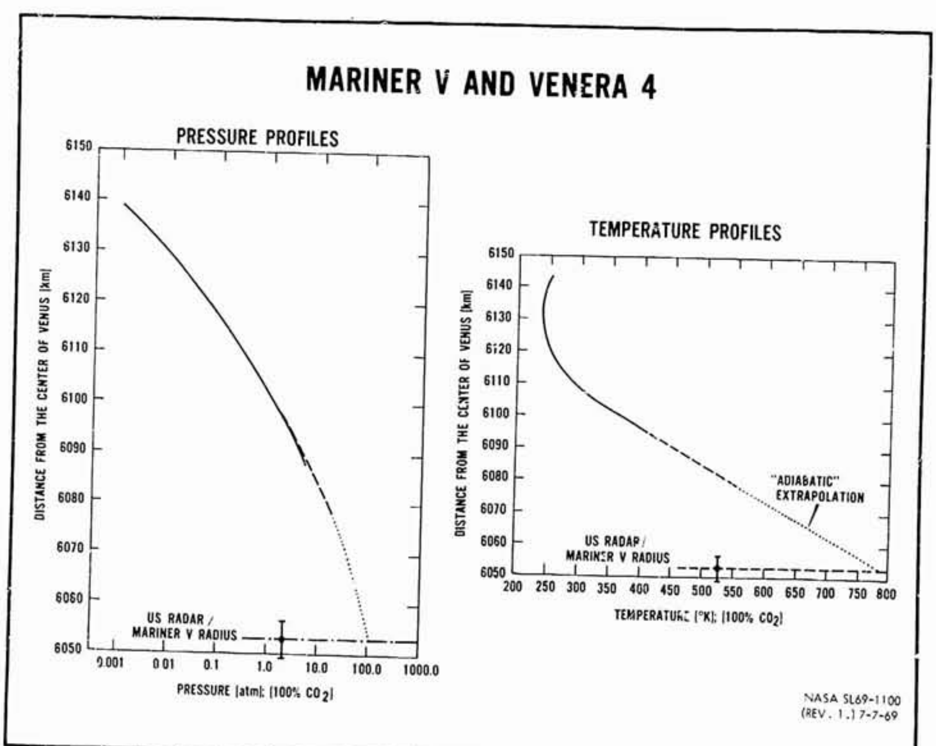


Fig. 16

In any case, when the measurements are extrapolated to the surface, one finds a pressure of approximately 100 atmospheres and a surface temperature of approximately 900°K.

There's no agreement yet on the origin of this high temperature. There are two theories which are currently in favor. The first one is the Greenhouse model. In this theory, the solar radiation which is not reflected to space is transmitted to the surface, absorbed, and converted into infrared radiation which is emitted. In the very massive atmosphere with its extensive cloud cover, most of the infrared is absorbed by the atmosphere. (Figure 17)

So, in order for the emitted infrared flux to match the solar flux absorbed by the surface, the surface temperature must be very high. There is a thermal blanket keeping the heat inside just as a greenhouse does--hence the name.

The second theory, which has been put forth by Richard Goody, involves differential heating. In this theory, the solar flux is deposited in the upper layers of the atmosphere, the deposition being greatest at the subsolar point, and decreasing toward the terminators where it is zero. (Figure 18)

Differential heating and associated motions have been studied on earth for problems in both the atmosphere and the oceans. In this scheme, the fluid rises at the subsolar point, comes around, and sinks at the antisolar point.

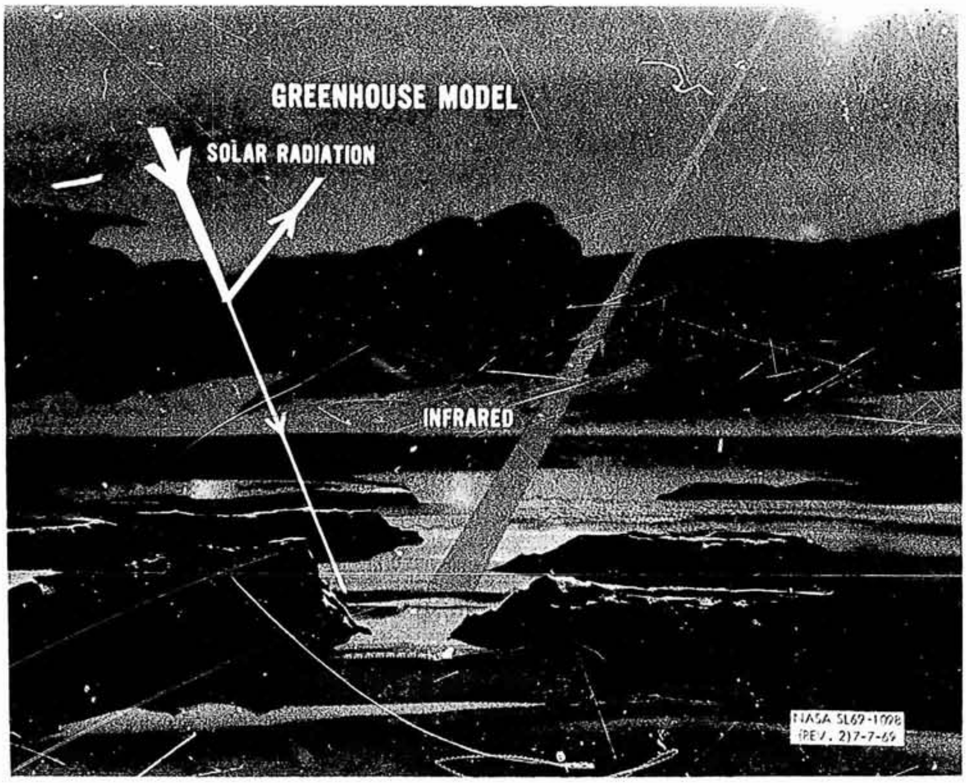


Fig. 17

If in fact this circulation pattern holds on Venus, the study of the energy aspects of the details of the circulation should provide us with insight into similar circulation patterns we have

If the Greenhouse model is applicable, the fact that CO_2 is a key factor in the energy transfer has application to a problem which may arise here on earth. This involves possible adverse effects resulting from the increase of CO_2 in our own atmosphere.

There have been only a few measurements of the carbon dioxide content. The ones shown in Figure 19 were taken from some work done at Mauna Loa in Hawaii. It appears that the CO_2 content is increasing at the rate of roughly 0.7 ppm per year and is currently at around the 320 ppm level.

The question is, what is the significance of this with respect to our own environment? Here are some calculations by two ESSA scientists. They have assumed constant cloud cover and relative humidity, and radiative energy transfer by CO_2 and H_2O. One sees that a change from 150 to 300 to 600 ppm doesn't change the lower temperature too much, but it does have a significant effect on the temperature of the stratosphere.

First impressions are that the immediate problem is not at all severe. However, with this kind of a buildup, if it continues and if these calculations are correct, then a potential problem certainly exists.

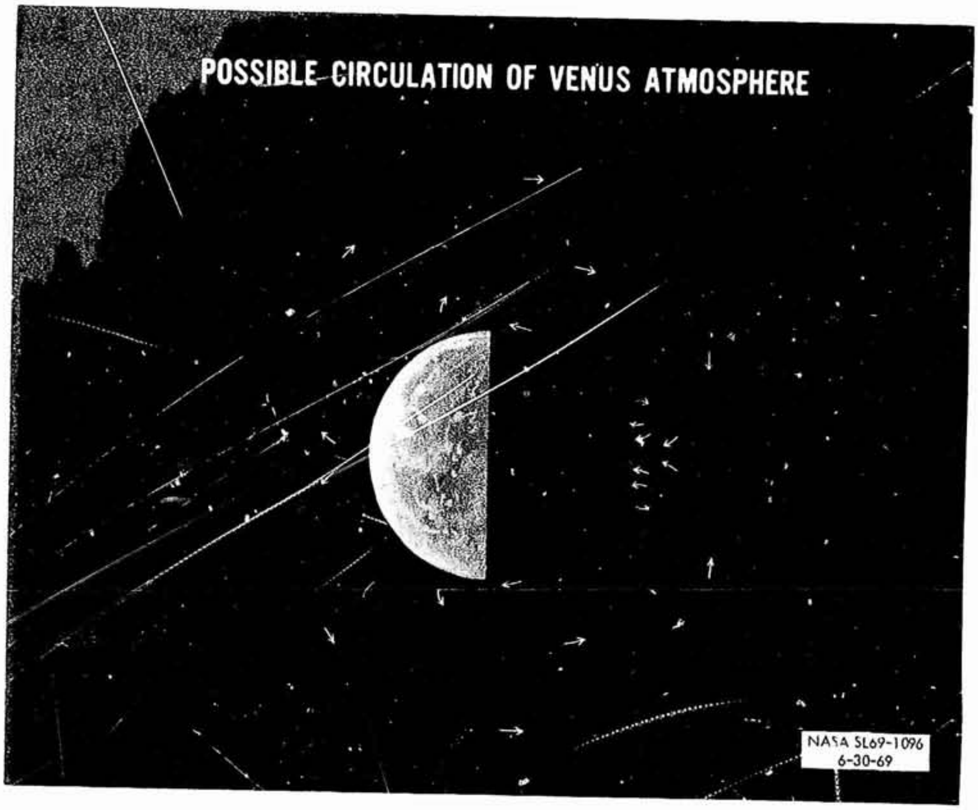


Fig. 18

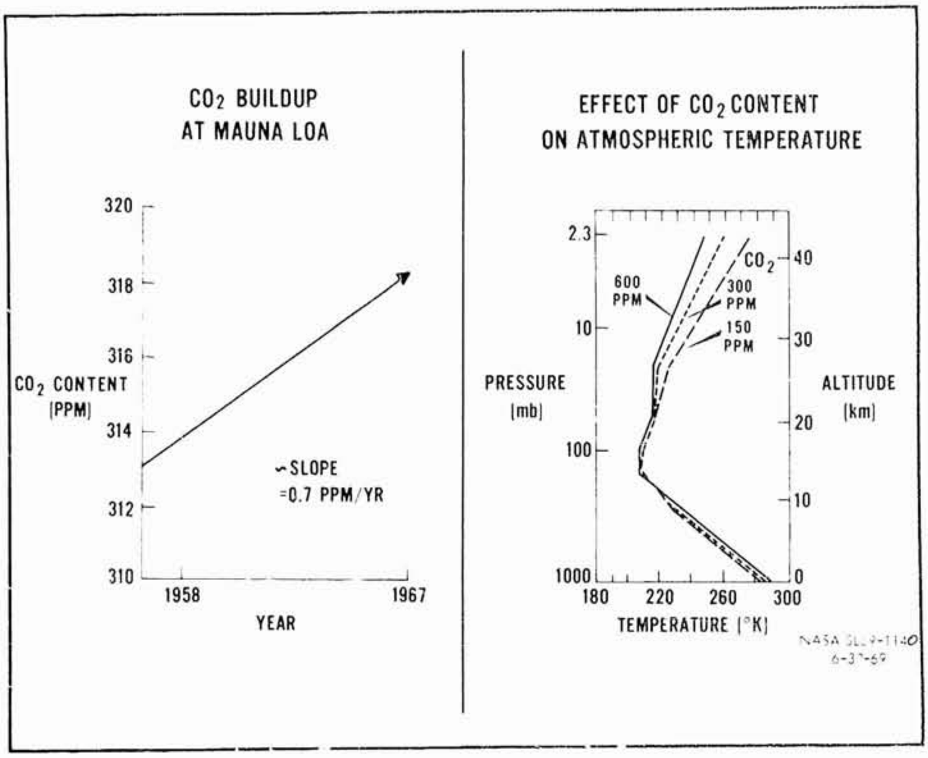


Fig. 19

Furthermore, we don't know if this buildup is constant and we are uncertain about some of the assumptions. There is no doubt, though, that understanding this effect better on Venus, if in fact it is the dominant mechanism, should provide insight into our Earth problems.

The second potential application I will discuss has to do with earthquakes. Figure 20 is a map of epicenters for the past 100 years or so, an epicenter, of course, being the central point of an earthquake.

You will see that the earthquakes are not random but occur in belts such as the mid-Atlantic ridge, west coast of the Americas, and the island chain in the Pacific.

In the course of the past few years, the mechanism involving continental drift has grown in favor for interpreting these earthquakes.

Figure 21 is a portion of an ancient continent--it is now believed that all of the present large land masses were once joined in a single, huge continent. A few hundred million years ago, this continent began to break up and started drifting apart.

It is believed that these parts are presently drifting at rates up to a few centimeters a year. Along the mid-Atlantic ridge material is coming up and spreading. Where there are great crustal blocks meeting one another, there is relative motion either laterally along the interfaces or vertically into the trenches.

EARTHQUAKE EPICENTERS

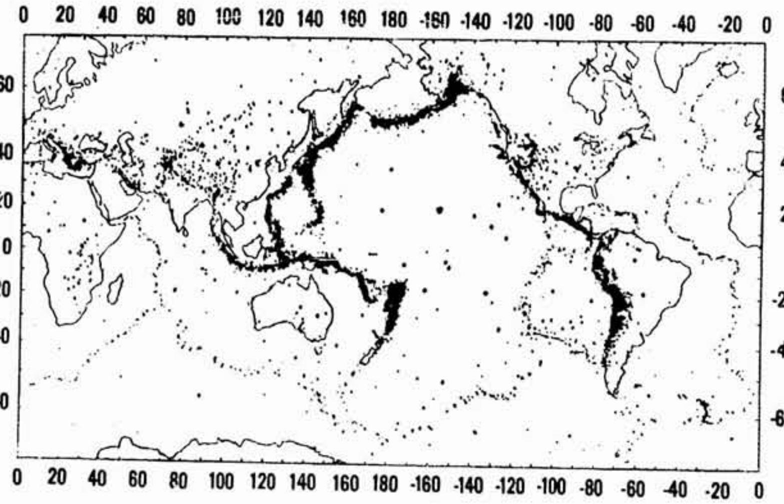


Fig. 20

AN ANCIENT EARTH CONTINENT

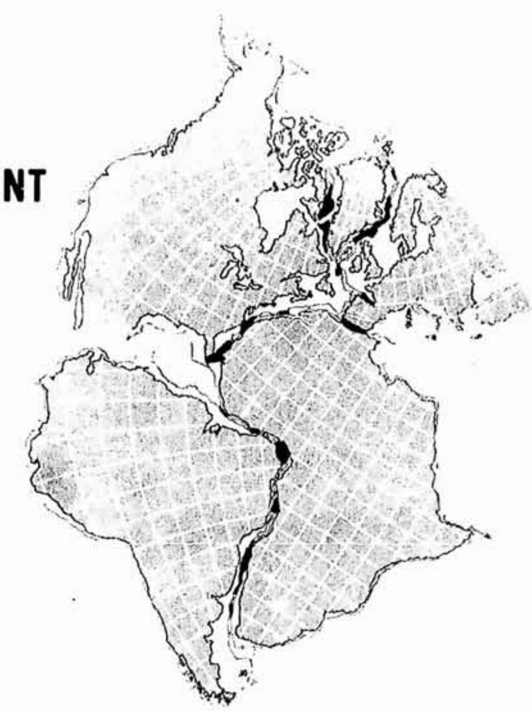


Fig. 21

The earthquake epicenters are concentrated along these boundaries. It is only in the last few years that this theory has really started to receive the attention of a significant number of scientists although the concept of continental drift has been around for a while.

Mars, it seems, has certain similarities to Earth which offer some potential for getting a better understanding of this drift phenomenon.

Figure 22 is a projection of the visual appearance with two radar strips superimposed. These are at 21° and 5° N. latitude They were obtained by the Haystack radar and depict the topographic elevations at these latitudes. The strips show two highs and two lows, very reminiscent of what one would observe for earth.

In fact, the M.I.T. scientists have analyzed the data and shown that the spherical harmonic coefficients are very similar to those calculated for earth.

This suggests that there are continents and "ocean" basins on Mars. There may then be motion of these continental blocks on Mars resulting in marsquakes. Studying marsquakes may be more straightforward than earthquakes because of the lesser erosion on Mars.

By getting these insights from Mars we will in turn get a better insight into the mechanisms that are operative on earth.

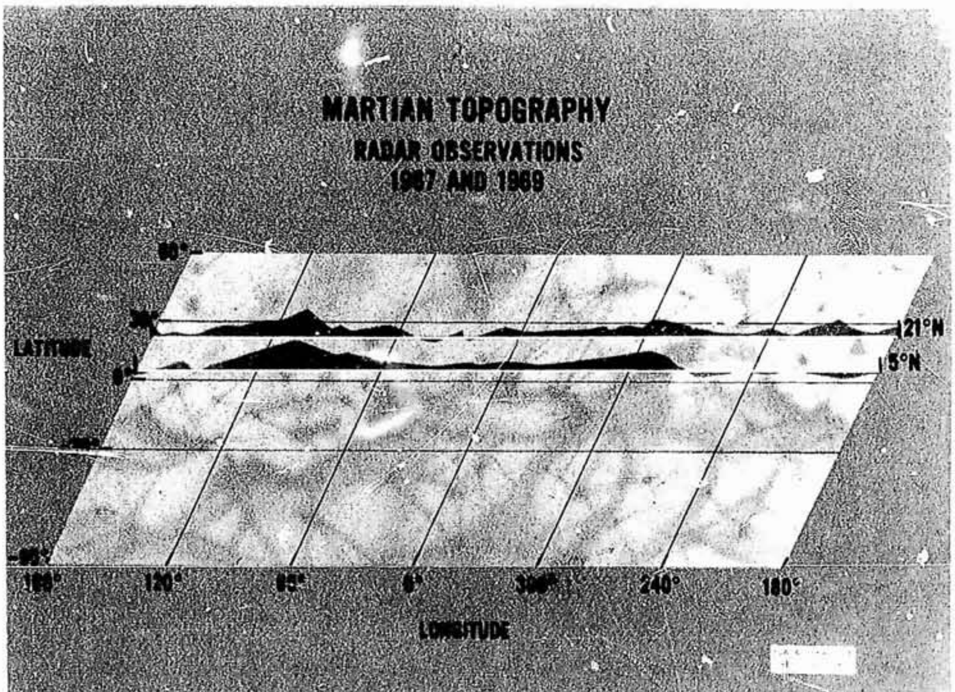


Fig. 22

INTRODUCTION - EARTH-BASED AND SPACE FLIGHT PROGRAMS

By: Mr. Donald P. Hearth

You've now heard a little about the solar system--what we know and more importantly about what we don't know.

What we'd like to do now is discuss what we are now doing and contemplate doing in the next 10 or 15 years to learn more about our solar system.

As an introduction to this part of the review, I'd like to talk about the techniques that one may use to explore our solar system. It's really a question of where man is relative to his instruments. (Figure 1)

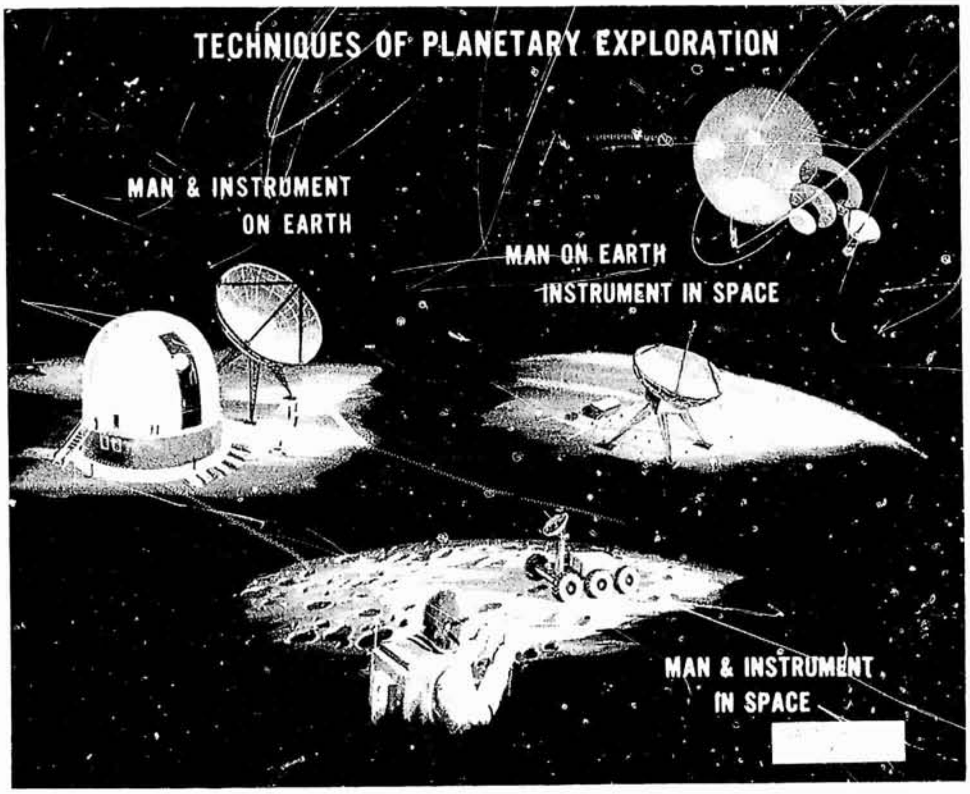


Fig. 1

Since the time of Galilec the use of earth-bound instruments is the technique that man has primarily used to explore the solar system.

In 1962 man sent his instruments into space toward the planets--but he himself stayed upon the earth. With the Apollo landing, in a matter of 10 days or so, man will join his instruments in the exploration of another body in the solar system. And no doubt the time will come when this technique will be used to explore planets such as Mars.

What we try to do is to weave together in an integrated way these various techniques, to move out, explore, and to learn.

I think Dr. Naugle has put it very well. He has said it is like playing an organ, in which you want to blend together these three different chords to get a harmonious tune.

Right now, in our planetary programs, we have a duet between the first two of these techniques. To review the first part of the duet we have Dr. William Brunk, who will discuss Planetary Astronomy.

PLANETARY ASTRONOMY

By: Dr. William E. Brunk

Dr. Rea discussed briefly the information we know about the planets, and also presented some of the problems that we need to solve in order to more fully understand the solar system. One of the techniques that can be used to solve some of these problems is to make observations from the earth.

Man has been interested in the planets for practically all of recorded history. He was able very early to distinguish the planets from most of the other objects in the sky, because the planets appeared to wander through the fixed stars. In fact, the word "planet" is derived from the Greek word for wanderer.

Figure 1 is an engraving from a book printed in 1504, it shows an early astronomer seated with the stars above him and the planets, indicated by their symbols, behind him.

EARLY ASTRONOMER

ARABIC ASTRONOMER MESSAHALLA
FROM STABIUS' SCIENTIA, NUREMBERG, 1504

Fig. 1

Man's knowledge of the planets was rather elementary until around 1600 when Galileo turned the first telescope towards the planets. Figure 2 shows a picture of two of his telescopes, mounted for display in a museum. He was the first man to observe and sketch the rings around Saturn, Jupiter and its moons, Mars, and the various phases of Venus.

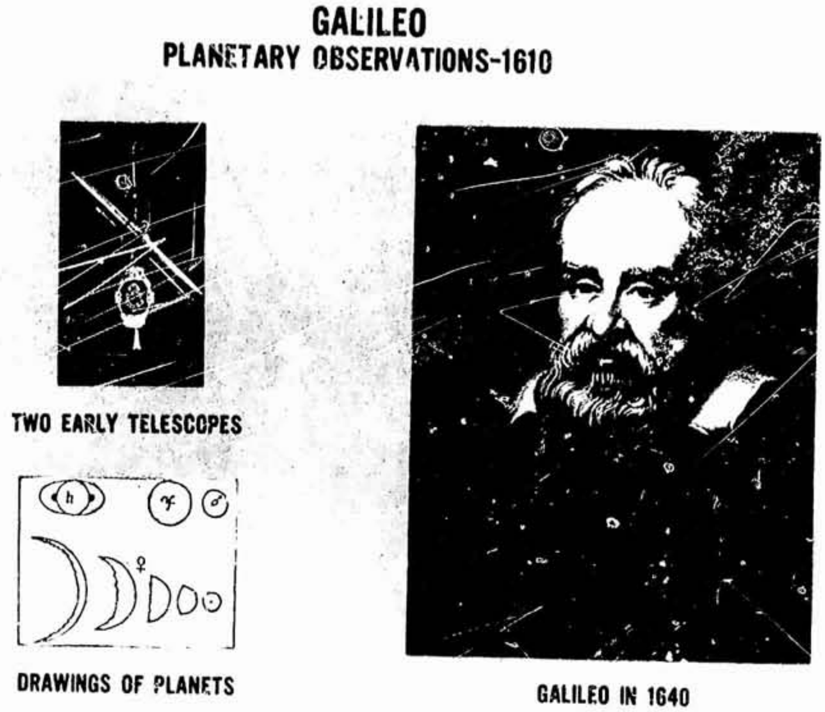


Fig. 2

Since the time of Galileo, there has been great interest in observing the planets and the astronomer has studied them as much as possible. However, the amount of information that could be obtained from ground-based observations has been somewhat limited, due primarily to two reasons.

The first limitation is the atmosphere itself, which is not a very good window. Figure 3 shows the transmission of the earth's atmosphere as a function of wavelength. The dark areas represent those portions of the spectrum where radiation cannot penetrate through the atmosphere; the light areas represent those portions where the radiation reaches the surface of the earth.

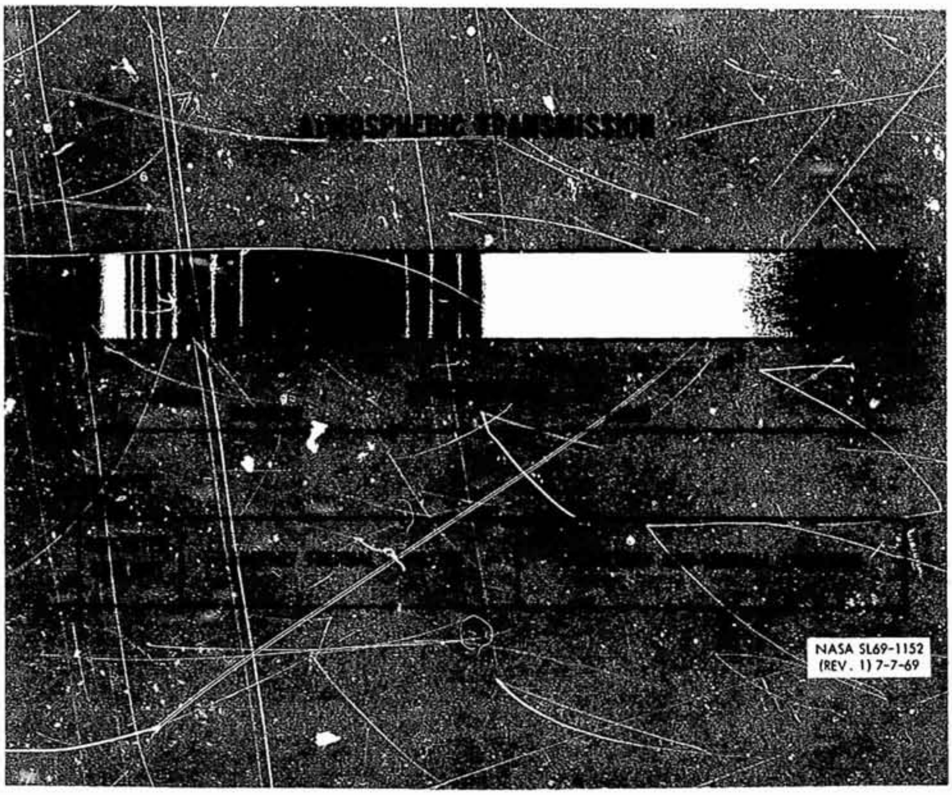


Fig. 3

On the left is the rather narrow optical "window" and on the right, the wide radio "window." In the infrared wavelengths there exist only some very narrow windows, and few of these have 100 percent transmission.

However, this limited transmission is no longer as serious an obstacle as it was several years ago, because we are now able to use other techniques to observe in those spectral regions where we cannot observe through the earth's atmosphere. Aircraft, balloons, rockets, and earth-orbiting satellites are used as observing platforms in and above the earth's atmosphere.

Now, why are we interested in observing the planets throughout the entire spectrum? The reason is that all regions contain information of interest.

In the ultraviolet we can observe emission lines produced in the planetary atmospheres, and from these we can determine properties of the atmospheres.

In the visible and near infrared regions the planet reflects sunlight, and we can observe planetary surface details, clouds, motions of these clouds, and other physical features.

In the infrared region, we observe thermal radiation from the planet itself, as well as absorption lines and bands due to molecules in the atmosphere of the planet. Also, in certain cases we can find out something about the composition of the surface material of the planet.

In the very long radio wavelength region, we can observe non-thermal radiation from the planet, that is, radio emission produced by processes not related directly to the temperature of the planet.

The second limitation on earth-based astronomical observations is due to technology. Since the year 1600 astronomers have been generally limited to working in the visible and near infrared as shown in Figure 4. In fact, it was not until 1955 that advances in technology enabled them to observe the planets outside of that spectral region. In 1955 the first radio signal from a planet was received. In 1961 the first radar return signal from a planet was clearly detected. In 1963 the first ultraviolet planetary spectrum was obtained from a rocket, and not until 1968 were astronomers able to observe the infrared spectrum of a planet from aircraft.

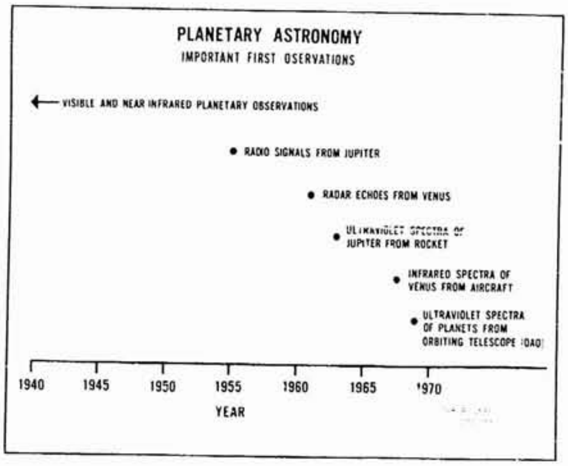


Fig. 4

Thus, advances in technology have enabled scientists to obtain much more information about the planets as observed from the vicinity of the Earth.

Now I will discuss briefly three examples of how knowledge of the planets that was known from ground-based observations prior to 1960 has had a major effect on the planetary flight program.

The first example concerns our knowledge of the surface temperature of Venus. Radio signals received from Venus at wavelengths between 1 and 10 centimeters, when plotted in terms of brightness temperature (Figure 5), indicate that the short wavelength radiation originates from a source at a relatively low temperature, and the longer wavelength radiation originates from a source at a much higher temperature.

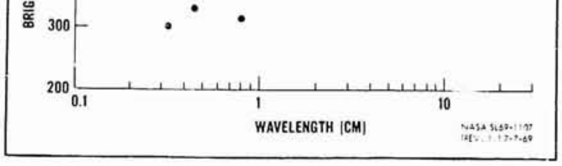


Fig. 5

The interpretation of this observational result is that the short wavelength radiation is coming from the upper part of the atmosphere of Venus, and indicates a low temperature for that part of the atmosphere (Figure 6). For wavelengths of 3 centimeters or longer, the source of radiation is primarily the surface of the planet, and this radiation gives an indication of the surface temperature of the planet. The intermediary values come from various levels in the atmosphere.

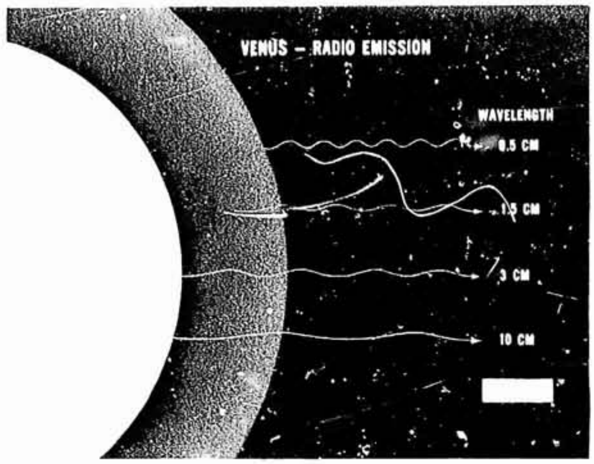


Fig. 6

Of what value is this result to the space program?

It means that a spacecraft that is expected to enter into the atmosphere and possibly land on the surface of Venus would have to be designed so it could withstand very high temperatures -- much higher than would be expected from simple theoretical considerations.

The second example has to do with the interpretation of the radio radiation from Jupiter in the wavelength range from 3 to 100 centimeters (Figure 7). When Jupiter was observed with radiotelescopes, it was found that the brightness temperature increased very rapidly with increasing wavelength. There was only one way to explain this result, and that was to assume that Jupiter had a strong magnetic field which contained high-energy electrons. Thus, it was concluded that there were radiation belts about Jupiter (Figure 8), very similar to the Van Allen belts about the Earth.

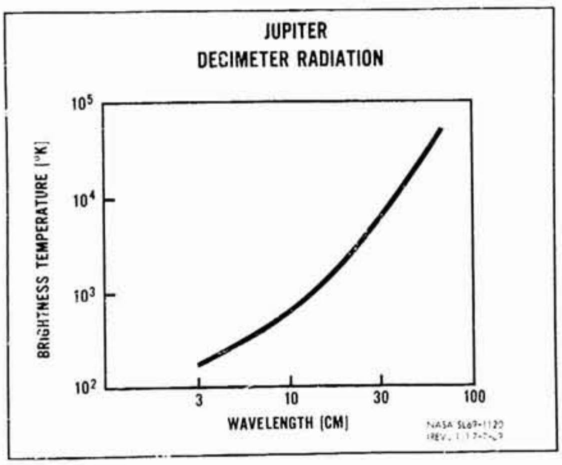


Fig. 7

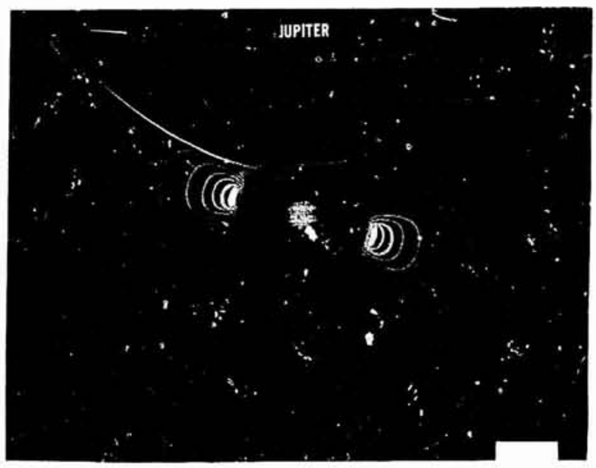


Fig. 8

This information affects the space program in the planning and design of spacecraft for Jupiter missions. The spacecraft have to be designed for operation in a strong magnetic field during the time of encounter, and the payload must include experiments to measure both the Jovian magnetic field and the charged particle content therein.

The final example is one where knowledge obtained from ground-based observations was used to interpret the results from a spacecraft experiment (Figure 9).

When Mariner IV flew past Mars in 1965, scientists were able to deduce properties of the Martian atmosphere from the analysis of variations in the radio signals received from the spacecraft. However, the only reason that the interpretation could be made relatively easily was that a great deal was already known about the properties of the atmosphere of the planet. Had nothing been known about the Martian atmosphere, it would have been almost impossible to interpret Mariner IV data in terms of atmospheric properties.

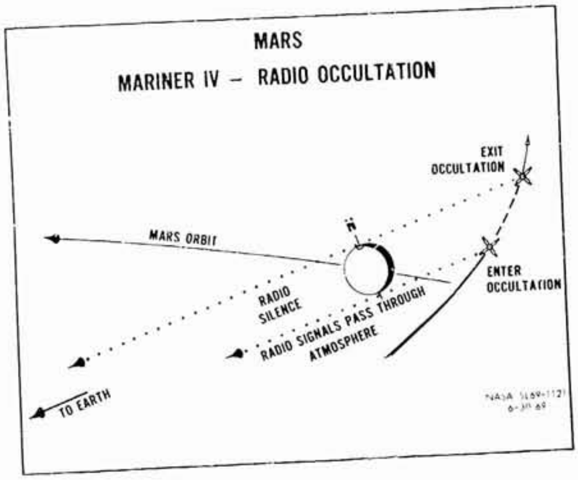


Fig. 9

The above examples involve information about the planets that we have known for some time. Now, I want to give you some examples of the information that we are finding today from ground-based observations, and how it is helping to answer some of the questions about the solar system.

One of the newest and most promising techniques to be applied to planetary astronomy is radar, and one of the first things that was discovered with radar was the rotation rate of the planet Venus (Figure 10). Prior to 1962, no one had been able to determine the rotation rate of that planet, because none of the standard techniques were usable. However, when the planet was observed with radar, it was determined that Venus had a very unusual rotation.

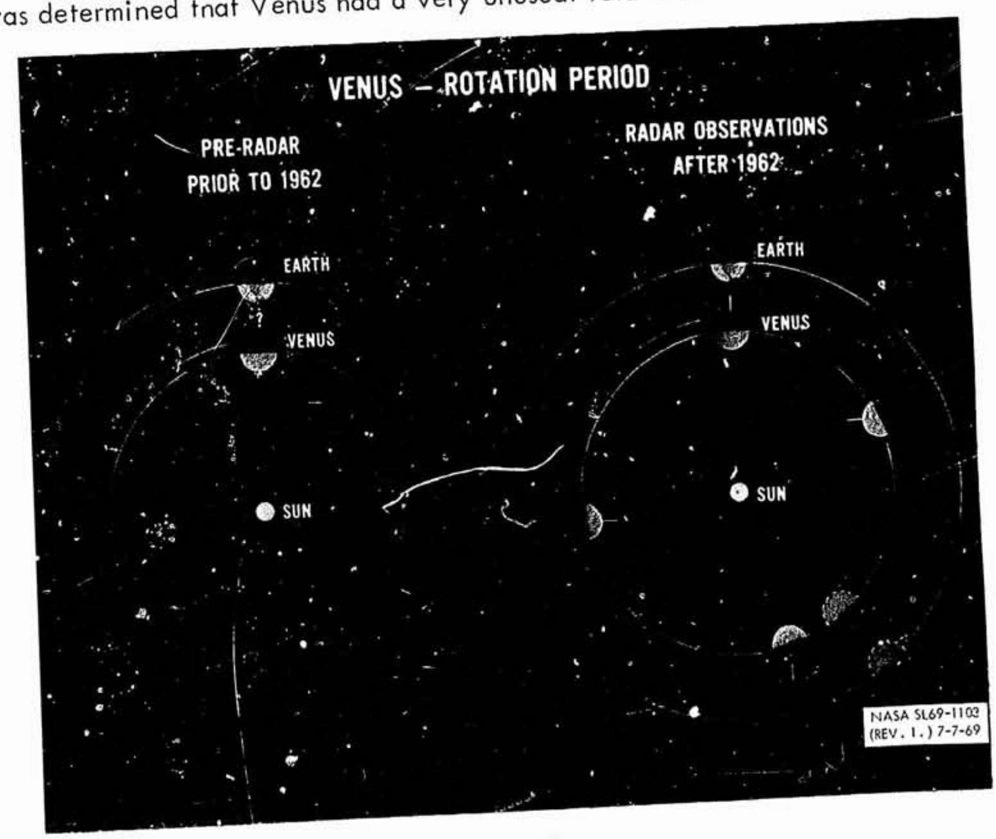


Fig. 10

Venus was found to rotate in a retrograde direction. The Earth and all other planets rotate in a counter-clockwise direction when viewed from the north; Venus rotates in a clockwise direction For an observer on Venus, the Sun rises in the west and sets in the east.

To illustrate this rotation, I have placed an imaginary tall, thin mountain on the planet and pointed it toward the Earth at the time when Venus is located directly between the Earth and the Sun. Approximately 56 days later, the mountain is pointing to the right in the figure. And 56 days later, it is pointing downward. The mountain does not point upward again on this figure until Venus has gone through more than one complete revolution about the Sun. The rotation period is 243 days while the period of revolution about the Sun is 224 days.

A day on Venus is approximately 116 Earth days long. Five hundred and eighty-three days from the time that the Earth, Venus, and the Sun are lined up as shown, they will be lined up again in the same relative position, but in the location shown by the dashed circles. At that time, the tall mountain will again point at the Earth.

This illustrates an unusual property of the Venus rotation. Whenever Venus is closest to the Earth, the same side of Venus faces the Earth. The rotation appears to be locked in some manner to the Earth.

The same radar technique was then used to look at the planet Mercury. However, we already "knew" that the rotation period of Mercury was 88 days. The rotation period and the revolution period about the Sun were the same. This had been determined from visual observations (Figure 11). In other words, if we again put an imaginary mountain on the planet and point it towards the Sun, the mountain will always face the Sun.

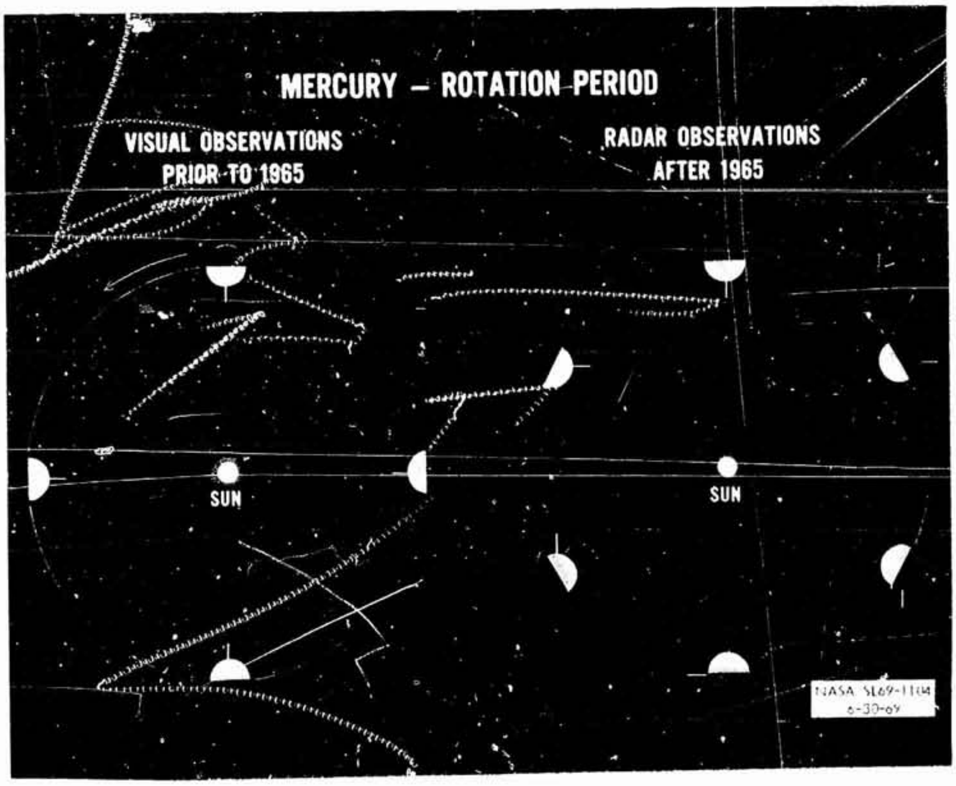


Fig. 11

However, the radar data indicated that 88 days was the wrong period of rotation, the actual period was 59 days. This result is illustrated on the right side of the figure. After travelling through approximately two-thirds of its orbit about the Sun, Mercury has undergone one full rotation with respect to the stars.

The interesting thing about this period of rotation is that in two revolutions around the Sun, Mercury makes three rotations about its own axis. The rotation is therefore locked in a unique way to its period of revolution around the Sun.

When astronomers went back and analyzed the visual observations, it turned out that these could also be interpreted in terms of the rotational period of 59 days. So the two types of observational data do not contradict each other, as it appeared at the beginning.

Recently an instrument has been developed to obtain extremely high dispersion spectra which are very useful for planetary studies. This instrument, called an interference spectrometer, when used together with a major telescope gave some very interesting and important information about the planet Venus.

Analysis of the spectra showed the existence in the Venus atmosphere of two minor constituents -- hydrogen chloride and hydrogen fluoride (Figure 12). The abundance of these constituents is very small, much less than one part per million.

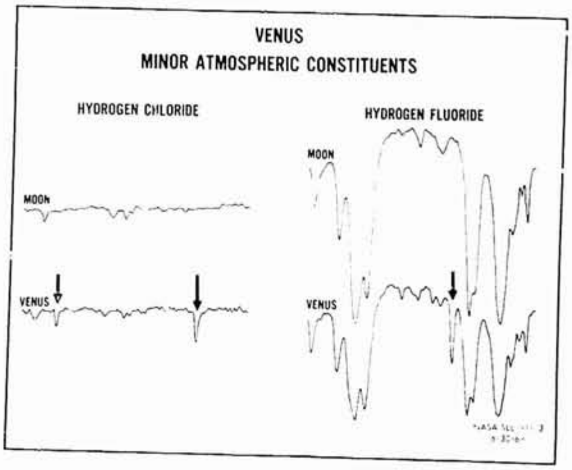


Fig. 12

What does it mean to find these minor constituents in the Venus atmosphere? In this particular case, the existence of these very highly reactive compounds in the outer atmosphere indicates that the temperature of the surface is probably very high. And, if the surface temperature is high, there is a strong probability that the mineral content of the surface is in chemical equilibrium with the lower part of the atmosphere. Therefore, by studying the outer part of the atmosphere, we are able to infer some information about the interaction between the surface and lower atmosphere.

Another very interesting result that was obtained just a matter of a few months ago was the positive identification of water vapor on Mars (Figure 13). Detection of the existence of water vapor on another planet is a difficult job. First, the water vapor lines for any planet lie at exactly the same wavelengths as the water vapor lines in our own atmosphere. Second, the Earth's atmosphere contains a large amount of water vapor, so that the lines are very broad and mask the weaker planetary lines. In the past it has not been possible to successfully separate the two components, the planetary component and the earth's component, of the water vapor lines.

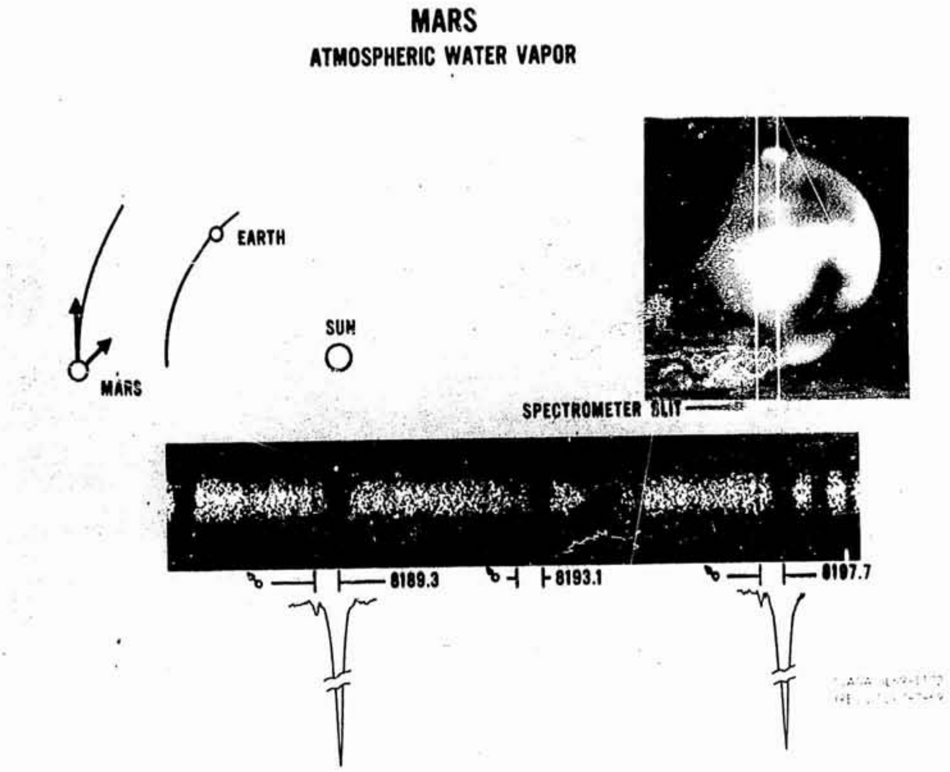


Fig. 13

However, combining the use of very high dispersion spectroscopy and making the observations when the planet has the maximum relative velocity toward or away from the Earth, it is possible to separate the water vapor lines due to the planet and the Earth. Complete separation of the lines also requires that the observations be made from a dry site on the Earth so that the Earth's water vapor lines are as narrow as possible. The segment of the spectrum shown in the figure contains three sets of water vapor lines. In each case, the faint line to the left is produced by water vapor on Mars. For two of the sets a tracing of the spectrum is given which shows very clearly the absorption lines.

The amount of water vapor on Mars producing these lines is approximately 25 microns. This is less than 1 percent of the water vapor above a very dry site on the Earth. The slit on the spectrograph that was used to obtain this spectra, was oriented in a north-south direction across the planet, thus permitting the relative amount of water vapor in the northern and the southern hemisphere to be determined. There was approximately twice as much water in the northern hemisphere as in the southern hemisphere at the time of observation.

Before completing the discussion of recent work, I want to mention two patrols that are underway at the present time.

The first patrol is a planetary photographic patrol (Figure 14). There are five stations located around the world (Figure 15), each equipped with telescopes of approximately 24-inch diameter, where the planets are photographed on a continuous basis during the night in order to study time varying phenomena, such as the formation and motion of clouds on Mars, the motion of the clouds on Jupiter, and other similar activity.

Fig. 14

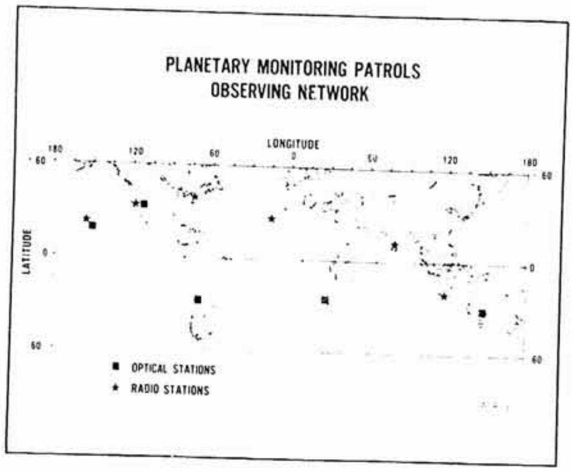


Fig. 15

The second patrol is a radio patrol using relatively simple Yagi antennas, located at six locations around the world, to study the very long wavelength radio storms from Jupiter, to determine whether there's any correlation between these storms and solar activity (Figure 16).

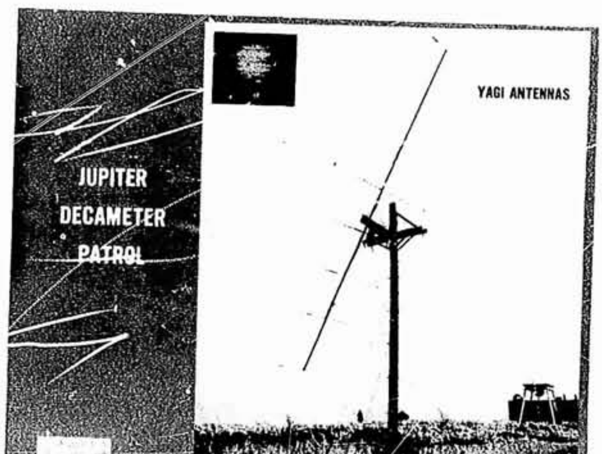


Fig. 16

Again, this is history, but very recent history. Now, what about the future? Have we come to the end of what we can learn from earth-based observations? The answer to that is an emphatic no.

I would like to give two examples of what could be done if we continue the work that has been started and also increase the available observational facilities.

It was pointed out by Dr. Rea that Venus, when observed at any wavelength other than in ultra-violet light, shows just a featureless disc. Nothing can be determined about the surface of this planet by observing it photographically (the left picture in Figure 17).

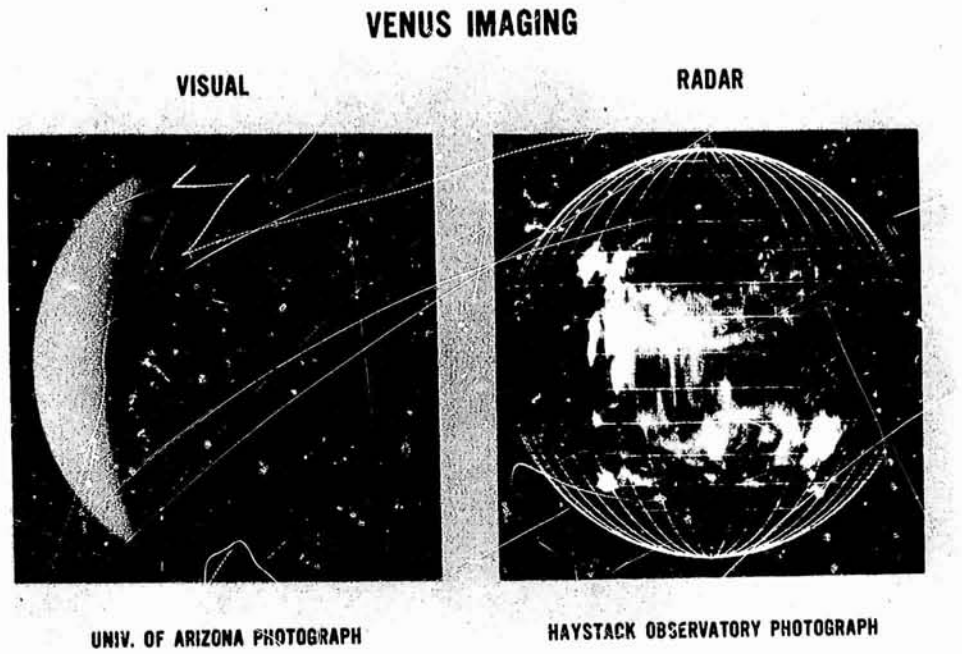


Fig. 17

However, using radar it has been possible to map areas of higher reflectivity on the surface of the planet by standard mapping techniques. The result is shown in the right hand photograph. The resolution on this photograph is about 100 to 150 kilometers. The bright spots are those areas that reflect the radar signal more than the surrounding area on the planet. They represent, most probably, mountains or some other large features.

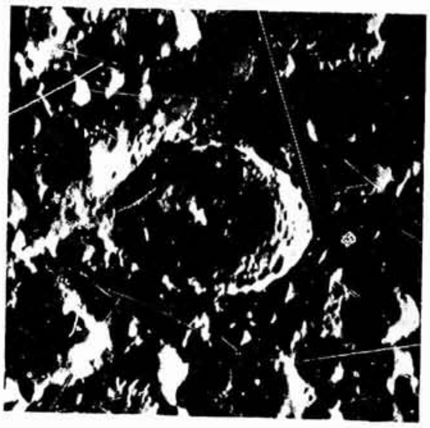
This radar mapping technique has been applied to the moon. Figure 18 shows an example of the results. On the left is a photograph taken from the earth of the crater Tycho and its vicinity and on the right is a radar image of the same region. The resolution of the radar image is about 2 kilometers, and of the photograph, about 1 kilometer

The same surface features, such as craters, are identifiable in both images. In the case of the moon, the radar image adds nothing new. However, if the moon were covered by an opaque atmosphere so that the surface could not be seen, it would still be possible to obtain the same radar image of the surface and thus "see" through the atmosphere.

Exactly the same technique can be used to observe the surface of Venus from the Earth, and a resolution of 2 to 5 kilometers on the surface of Venus could be obtained. This, however, is only possible if we are able to upgrade a large radar telescope like the 1000 foot diameter antenna at the Arecibo Radio Observatory in Puerto Rico by improving the antenna so that it is operational at a shorter wavelength and by modifying the feeds and the transmitters (Figure 19).

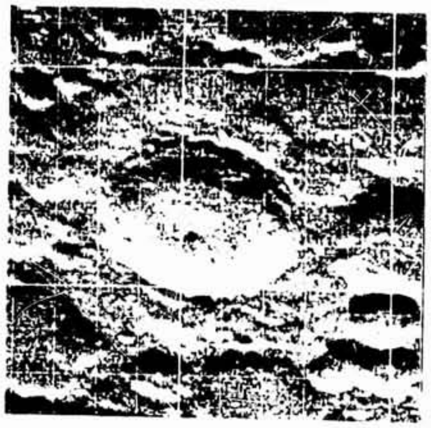
RADAR IMAGING OF MOON
CRATER TYCHO AND VICINITY

PHOTOGRAPH



UNIVERSITY OF ARIZONA
PHOTOGRAPH

3.8 CM RADAR IMAGE



HAYSTACK OBSERVATORY
PHOTOGRAPH

Fig. 18

ARECIBO IONOSPHERIC OBSERVATORY
1000 FOOT DIAMETER ANTENNA

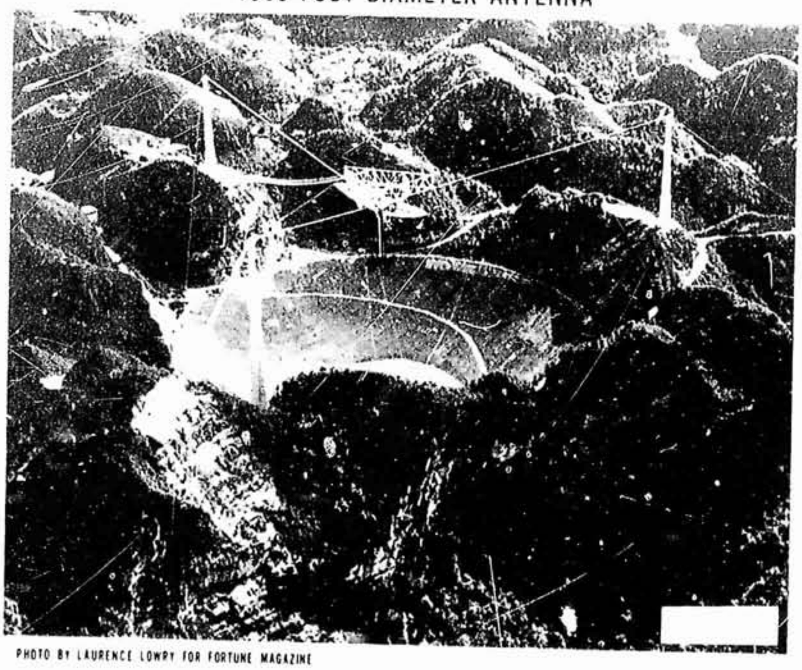


PHOTO BY LAURENCE LOWRY FOR FORTUNE MAGAZINE

Fig. 19

The other example that I would like to disucss is the area of infrored observations. This region of the spectrum is important for planetary observations as it is the region where the planet radiates most of its energy as well as where absorption lines are produced by molecules in the planet's atmosphere.

In Figure 20 the top, center curve shows the infrared solar spectrum as it would appear from above the atmosphere. However, if you observe the sun from an observatory located at an altitude within a few thousand feet above sea level, you would get the bottom curve where a large portion of the solar spectrum is obscured due to strong absorptions by water vapor and carbon dioxide in the earth's atmosphere.

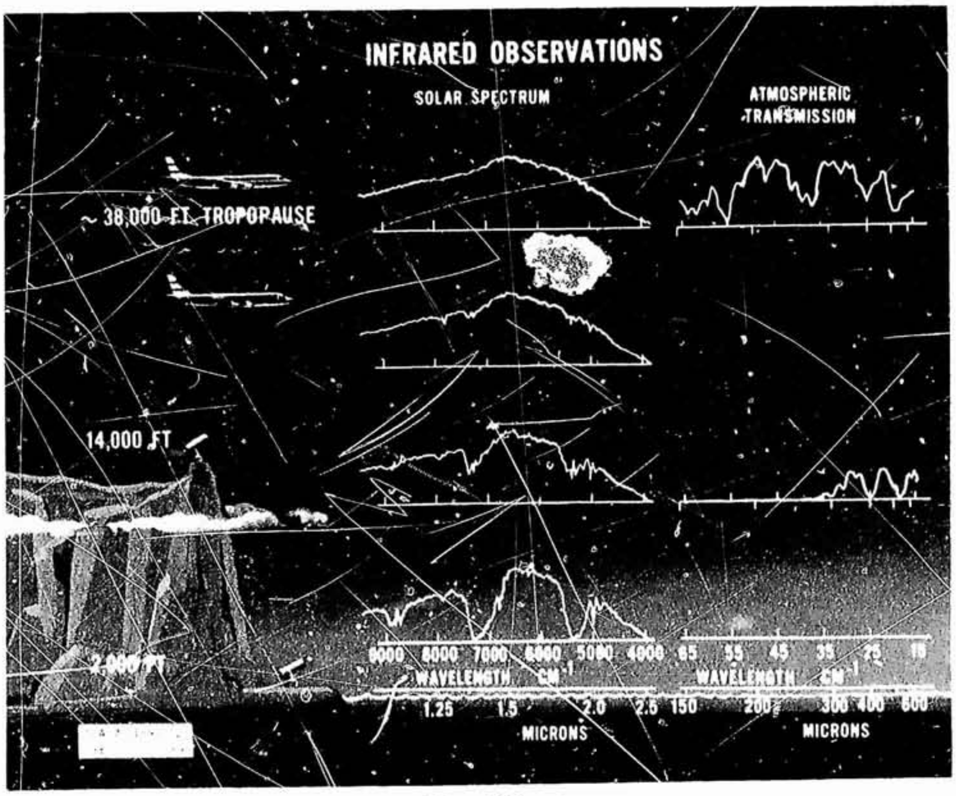


Fig. 20

At higher altitudes, such as 14,000 feet, and relatively dry sites, much of the atmospheric absorption is eliminated as you are located above a large percentage of the atmospheric water vapor.

We are making use of the reduced absorption available from such a site by installing an 88-inch telescope on Mauna Kea, in Hawaii (Figure 21). This telescope is located at an altitude of not quite 14,000 feet and the site is extremely dry. In fact, most of the measurements made at the site show no measureable water vapor. The telescope will be used primarily for infrared spectroscopy of the planets.

UNIVERSITY OF HAWAII
MAUNA KEA OBSERVATORY
88-INCH TELESCOPE

Fig. 21

It is possible to eliminate almost all of the unwanted absorption by going to still higher altitudes which can be done by installing a telescope in an airplane.

If observations are made from above the tropopause, there is practically no adverse effect at these wavelengths due to absorption on the earth's atmosphere. However, if observations must be made from below the tropopause, a small adverse effect remains due to the increase in water vapor content at the altitude of the tropopause.

Infrared planetary observations have been made at approximately 40,000 feet altitude using the NASA Convair-990 aircraft, a large research airplane operated by the Ames Research Center (Figure 22). Several of the viewing windows can be seen along the top of the airplane.

At the present time a 36-inch telescope is under construction which is to be carried on this airplane. However, a ma problem exists with the use of the Convair-990 as it is limited to a maximum altitude of abo 41,000 feet. The altitude of the tropopause changes with latitude and time of the year. Much of the time it is above 41,000 feet and the airplane must fly below it.

If the telescope were mounted in an airplane that could fly at a higher altitude, then it would always be possible to fly above the tropopause. Such an aircraft is the Lockheed C-141 "Starlifter," which has a maximum altitude of about 50,000 feet (Figure 23). It can also fly at maximum altitude for about twice the length of time as the Convair-990, 6 hours rather than 3, and can carry a much larger payload.

NASA CONVAIR 990

Fig. 22

LOCKHEED C-141 "STARLIFTER"

Fig. 23

Up to now, I have been discussing observations at the shorter infrared wavelengths. At the very long infrared wavelengths, there is no transmission at all through the atmosphere at sea level. At altitudes of 14,000 feet there is no transmission through the atmosphere for wavelengths below 300 microns and about 50 percent transmission at longer wavelengths. For observations from above the tropopause, the atmospheric transmission is high, between 50 and 100 percent, at all wavelengths. It is, therefore, possible to observe at almost all infrared wavelengths from high-altitude aircraft.

Now, it is obvious that it is still possible to learn a great deal about the planets from earth-based planetary astronomy. However, there are certain very definite limitations. It is obvious that in situ measurements of the planets can not be made. Also, because of the geometry of the solar system it is not possible to observe the outer planets at any but almost full phase.

There is also a limit to the spatial resolution which can be obtained from the vicinity of the earth regardless of the instrumentation used. I would like to illustrate the effect of resolution limitations using the following photographs.

Figure 24 is a photograph of the earth taken by an ATS satellite. The resolution on the earth is about 2 miles. In other words, two points on the earth's surface would have to be at least 2 miles apart before they could be distinguished as two separate points.

ATS-III: THE WESTERN HEMISPHERE ON JANUARY 21, 1968

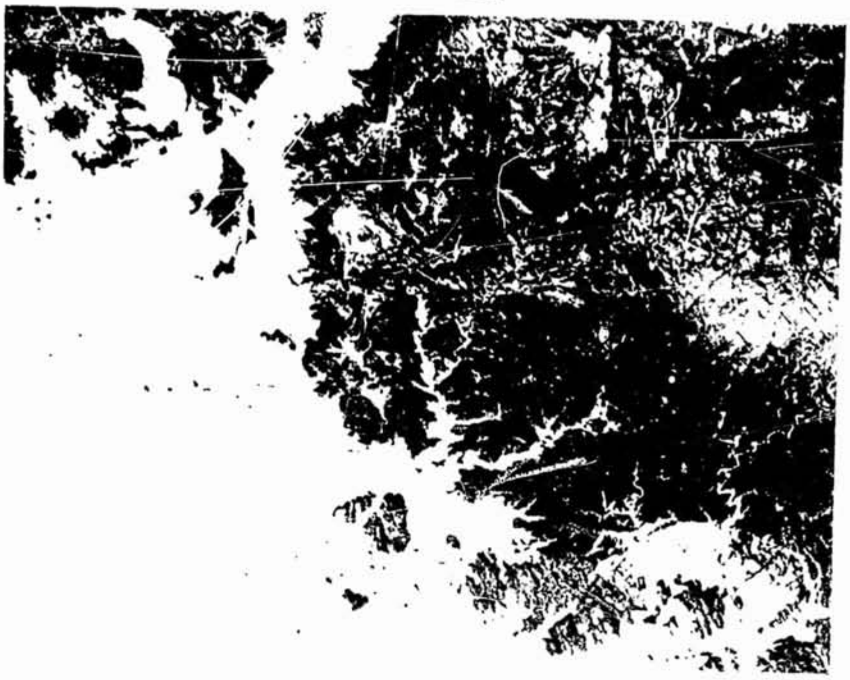
Fig. 24

Keep this picture in mind as I illustrate the effect of decreasing resolution. Figure 25 is a photograph of Saudi Arabia with a resolution of 10 meters. On the left there is a desert region, and on the right, an upland region.

Figure 26 shows the same photograph with the resolution decreased by a factor of ten. Note that the lighter portion of the upland region (see right side of Figure 25) is now almost indistinguishable from the desert regions on the left side.

This is approximately the difference in resolution that you would have in looking at Mars at maximum obtainable resolution, as compared to the ATS photograph of the Earth.

SAUDI ARABIA

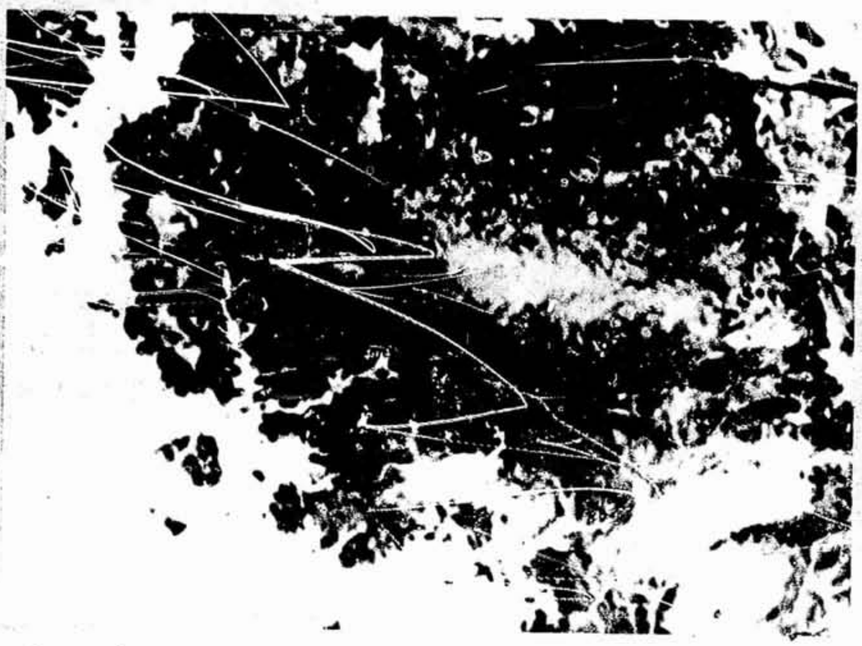


RESOLUTION 10m

NASA SL 67-1947
2-14-67

Fig. 25

SAUDI ARABIA



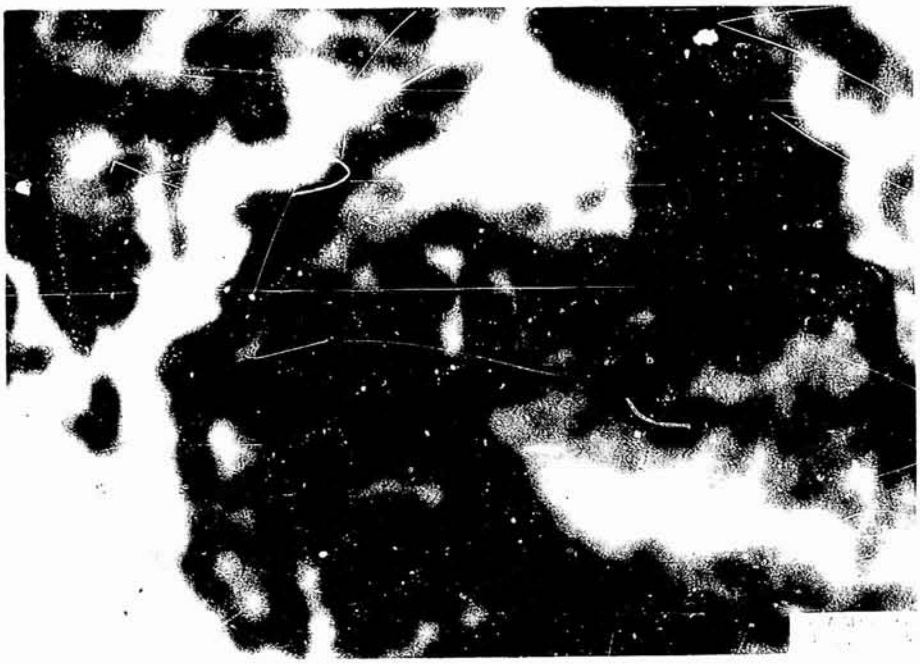
RESOLUTION 100m

NASA SL67-1948
(REV. 1) 7-7-69

Fig. 26

To consider the maximum resolution possible on Jupiter from the Earth, we must decrease the resolution again by about a factor of ten. Such a decrease would affect our picture of Saudi Arabia to almost the extent shown in Figure 27. Here it is not possible to differentiate between the desert and many parts of the uplands.

SAUDI ARABIA



RESOLUTION 1.4km

Fig. 27

This poorer resolution is indicative of the best we could ever do in observing any planet as far from the Earth as Jupiter. Thus, high resolution studies of any planet must be made from the vicinity of the planet.

For this and other reasons, complete understanding of a planet requires observations and in situ measurements made from planetary spacecraft.

SPACE FLIGHT PROGRAM

By: Mr. Robert S. Kraemer

Dr. Brunk has described for you the use of far-seeing telescopes for the study of the planets from Earth. During just the past several years, we have established the practicality and value of a second tool, automated spacecraft, to fly to the planets and study them directly with close-up observation. I will briefly summarize for you the past, the present, and the future use of such spacecraft in the direct exploration of the planets.

History of Planetary Flight

In contrast to the centuries of experience in planetary astronomy, the first man-made spacecraft reached another planet only 6-1/2 years ago. The direct exploration of the planets is still very much in its infancy but maturing rapidly.

The Russians were the first to attempt to launch to another planet, with an attempt at a Mars flight on 10 October 1960. This attempt was a failure and so were their next 15 planetary attempts, stretching over a period of 7 years.

The successes to date in the United States (US) planetary flight program are shown in Figure 1. We started with two Mariner spacecraft launches to Venus in 1962, just 7 years ago. On the launch of Mariner I, the Atlas-Agena launch vehicle veered off course and had to be destroyed

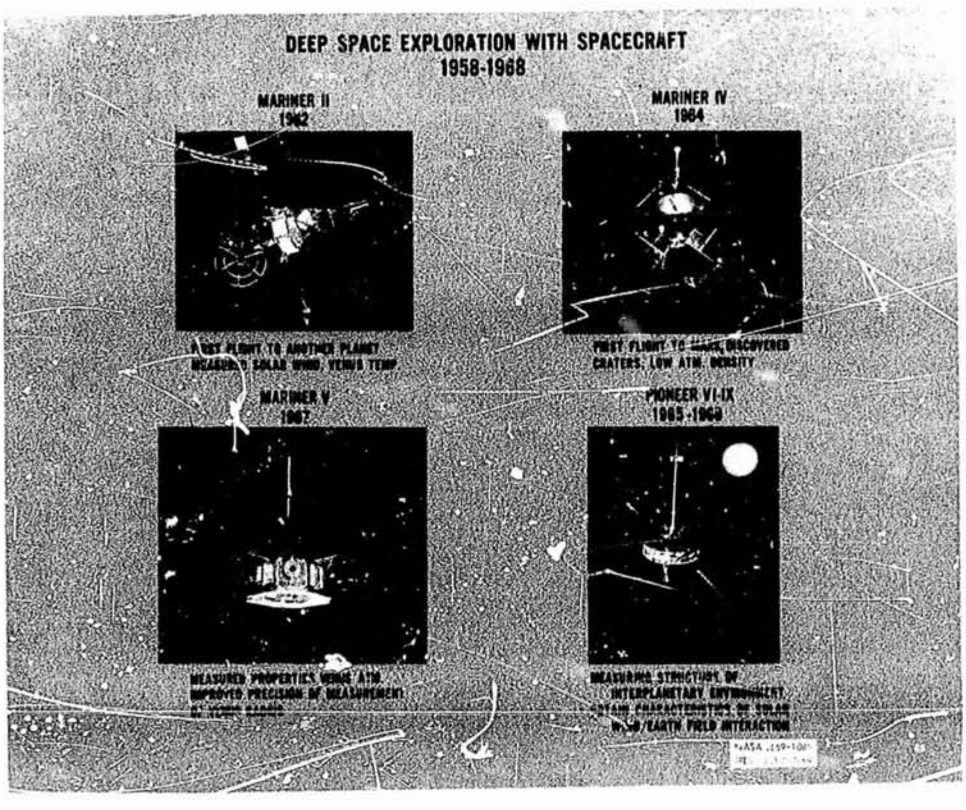


Fig. 1

by the range safety officer -- a rather discouraging beginning. However, we were able to diagnose the troubles, correct them, and successfully launch Mariner II on its way to Venus just 5 weeks after the Mariner I attempt. The Mariner II flight was far from trouble-free. The Atlas-Agena started to roll during launch and was more than a little lucky to burn out on an acceptable trajectory. The spacecraft itself then developed a series of anomalies -- it kept attempting to lock on to the wrong celestial objects, the solar panels began to short out, and the spacecraft seriously overheated as it ventured in toward the sun. Some of these problems were corrected by Earth command and others just seemed to correct themselves. It is a common saying at the Jet Propulsion Laboratory (JPL) that Mariner II got to Venus not with radio guidance, stellar guidance, . inertial guidance, but rather by "divine guidance." In any event, by the time the spacecraft reached Venus, it was in satisfactory functioning condition and made very successful measurements of the planet. Some of the results of these measurements were unexpected, such as finding no magnetic field at Venus, and other measurements confirmed earlier indications such as a very hot surface temperature on Venus.

We next tried a pair of launches to Mars in 1964. For these flights the Mariner spacecraft was provided with a newly designed fiberglas honeycomb shroud. The Mariner III spacecraft was unable to separate from that shroud after launch. With round-the-clock effort, a new magnesium shroud was designed, built, tested, and delivered to the Cape in just 17 days for the launch of Mariner IV. The flight of Mariner IV was quite trouble-free and highly successful. It is probably most noted for returning the rather startling TV pictures showing the surface of Mars to be cratered much like the Moon. Dr. Rea has just shown you some of these pictures.

In 1967 we returned to Venus to make refined and extended measurements with the Mariner V spacecraft. This was a picture-perfect flight and highly successful. Its timing was especially fortuitous in that the Russians attained the first partial success in their planetary program when the Venera IV probe entered the Venus atmosphere within hours of the Mariner V flyby. The Russians immediately claimed that Venera IV had reached the surface of Venus, measuring a surface pressure of about 20 atmospheres. The Mariner V results coupled with Earth radar measurements said that this was just not so, that the surface pressure at Venus had to be at least 100 atmospheres. Following the Venera V and VI entry attempts into the Venus atmosphere in early 1969, the Russians have now admitted that Mariner V was correct and that all three of their Venera probes have collapsed due to high Venus atmospheric pressure before reaching the surface.

In addition to the Mariner flights, we have also launched a series of Pioneer spacecraft along the path of Earth's orbit around the sun to form a "space weather" network. All four of these Pioneers launched since 1965 are still functioning and are being utilized in the Apollo program to give advance warning of dangerous solar flare activities.

I would now like to relate these past achievements into the picture of our total planetary exploration objectives, making use of the progress chart or "score card" shown in Figure 2. As one scale of this matrix, I have listed the planets and major objects in the solar system in an approximate order of priority. This priority is a somewhat arbitrary combination of scientific interest and accessibility. For example, the first four planets listed, Mars, Venus, Jupiter, and Mercury, also happen to be the planets closest to Earth and most easily reached with flight spacecraft. The left-hand vertical column of this Figure lists the specific scientific objectives and measurements that we must make to answer the more pressing questions outlined by Dr. Rea. Along side these scientific objectives are listed the vehicles or missions generally required to make the

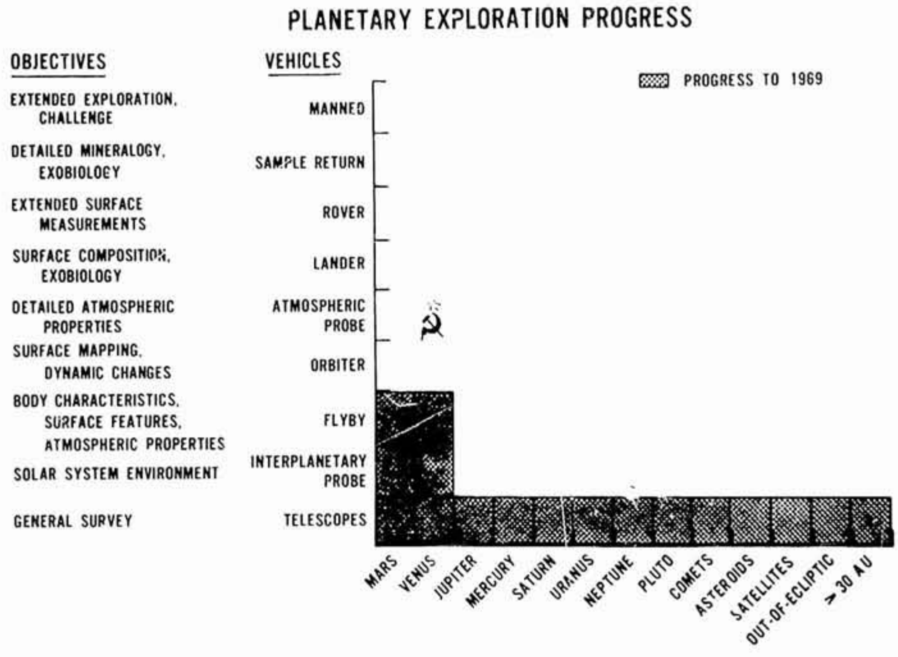


Fig. 2

measurements. For example, the measurement of "detailed atmospheric properties" normally requires an "atmospheric probe" which directly enters the atmosphere in question.

The vehicles are listed in an order of increasing sophistication in cost from bottom to top. For example, the flight of a flyby or orbiting spacecraft is more expensive than the use of a telescope, and a lander mission is more expensive yet. Thus, it behooves us to stay as low on the list as possible for any given measurement. The actual choice of vehicles and missions turns out to be a function of the properties of the particular planet. At Mars, with its thin atmosphere, we can obtain a good deal of atmospheric information using Earth-based telescopes, as already described by Dr. Brunk, and still more with flyby and orbiting spacecraft, so that those measurements which have to be made with an atmospheric probe can be minimized. At Venus, however, with its very thick opaque atmosphere, we are quite limited in our measurements with telescopes or flyby and orbiting spacecraft, and will have to depend heavily on the use of atmospheric entry probes.

The extent of our planetary exploration progress up to 1969 is plotted on this Figure. We are well along in a good general survey of all the planets using Earth-based telescopes. We have also sent flyby spacecraft through interplanetary space to the planets Mars and Venus.

The Russian contribution to date has been three Venera probes which entered part way into the atmosphere of Venus. The latest version of those Venera spacecraft is shown in Figure 3. Notable features include the spherical entry capsule at the bottom of the assembly, the propulsion subsystem under the conical shroud at the top, the protruding solar panels behind which is the high gain antenna, and various scientific instruments mounted about the spacecraft assembly. This vehicle is quite large, weighing almost 2500 pounds, or about five times the weight of our early Mariners and three times the weight of our Mariners currently flying to Mars.

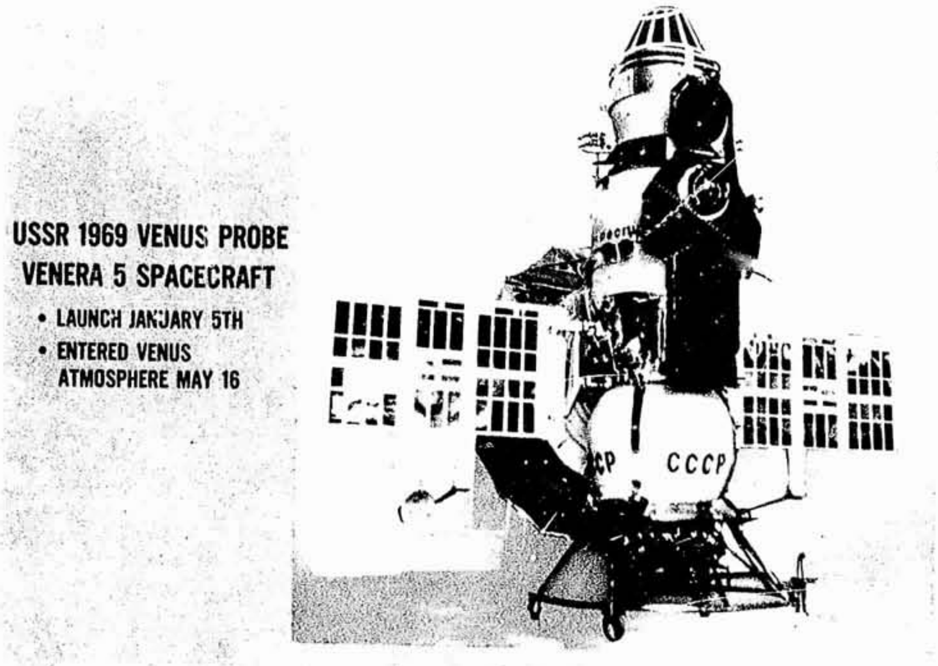


Fig. 3

Fiscal Year 1970 Program

Coming from the past to today, Fiscal Year 1970, I would like to describe for you the ingredients of our present program. Let us start with the top priority planet Mars. Certainly Mars still rates this highest priority, being a most interesting dynamic planet with changing seasons much like Earth's. Moreover, the recent positive measurement of water in the atmosphere of Mars further solidifies its position as the most likely planet in the solar system for finding extraterrestrial life.

Our presently approved Mars program is summarized in Figure 4. We currently have two Mariner spacecraft on their way to Mars. Mariner VI will reach its closest encounter altitude of approximately 2000 miles on 31 July. Mariner VII will flyby Mars at a similar distance on 5 August. These will be followed in 1971 by a pair of Mariner spacecraft incorporating larger propulsion subsystems to place the spacecraft into long-life orbits for long term study of the dynamic planet Mars. In 1973 under the Viking program we will not only orbit Mars, but we will achieve a longstanding goal in landing our first set of automated instruments directly onto the surface.

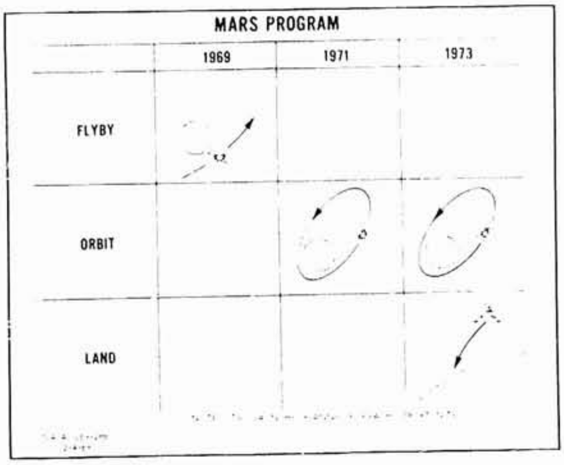


Fig. 4

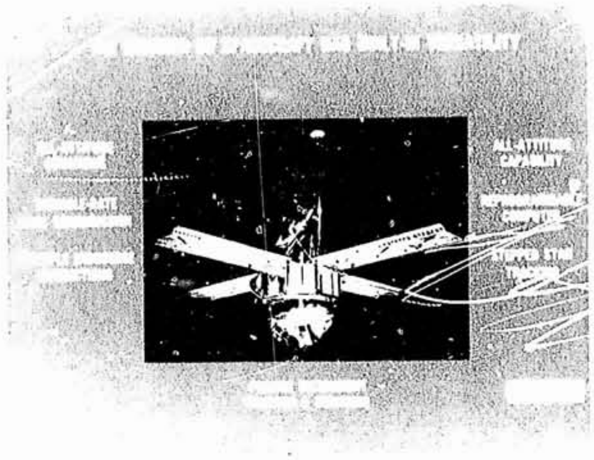


Fig. 5

Now you will note that in this program the Mariner spacecraft play a strong role throughout, going from a flyby in 1969 to orbiting in 1971, and finally the delivery of the lander capsule in 1973. Some of the reasons we are able to accomplish these diverse functions with the Mariner spacecraft are illustrated in Figure 5. During the 1960's the Mariner spacecraft has evolved into a highly versatile machine. Several of the features that permit great flexibility of operation are noted in the Figure. For example, a reprogrammable computer allows the spacecraft to function in any desired sequence, and we can even modify this sequence as desired after launch, as we have already done with Mariner VI and VII. With this sequence control, the all-attitude capability, and the scan platform on which the science instruments are mounted we can fully optimize the science return during a planet flyby or orbit.

The scan platform can rotate about its vertical axis and can also be rotated through 70° on a plane through this axis. The desirability of this degree of pointing control can be better understood by looking at Figure 6, which shows the instruments on the Mariner 69 scan platform. These Mariners are carrying a complement of highly sophisticated instruments, including wide angle and high resolution television cameras, spectrometers in both the infrared and ultraviolet, and an infrared radiometer. For best results, these instruments do not all want to scan the exact same portion of the planet. With the full pointing control of the Mariner spacecraft, we can direct each of these instruments in turn for best results, as illustrated in Figure 7. As the spacecraft approaches and then passes the planet, we can keep the solar panels pointing toward the sun, the high gain antenna pointed toward earth, while pointing the instruments in the desired modes.

Approaching the planet, the television cameras are turned on several days before the nearest encounter so that the lighted area of the planet can be studied through several Martian days. Also in the field of view will be Phobos, one of the two known moons of Mars, but it is so small that it will probably just show up as a tiny point of light. Approaching closest encounter, the full complement of instruments is activated, scanning various portions of the planet to return the best data on surface topography, atmospheric properties and constituents, and surface temperatures. During viewing of the south polar cap by Mariner VII, measuring its temperature and the constituents of the near-surface atmosphere, we hope to pin down the cap's composition, whether it be dry ice, water ice or a mixture of both.

MARINER 69
SCAN
PLATFORM

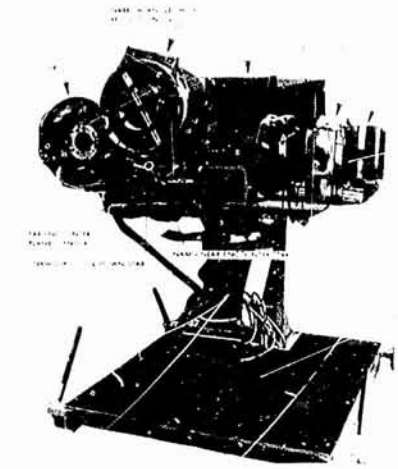


Fig. 6

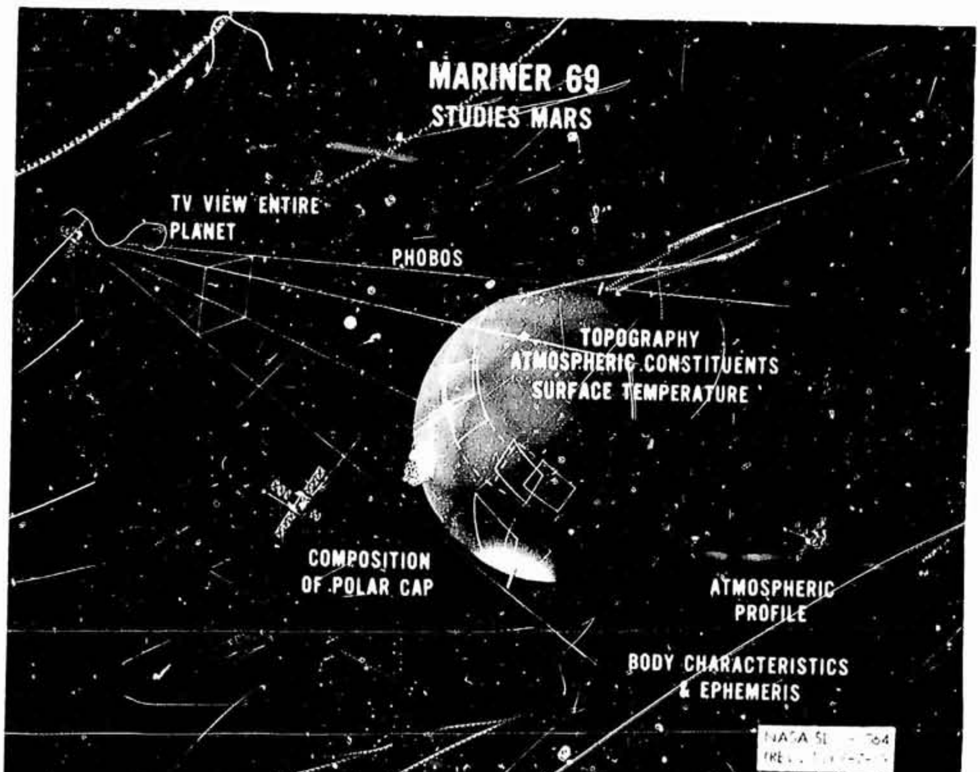


Fig. 7

Measurements will also continue after leaving the planet. The radio beam from the spacecraft back to Earth slices down through the atmosphere of Mars before being occulted or cut off at the surface as the spacecraft swings out of view behind the planet. Through careful analysis of this radio signal, we are able to determine the atmospheric profile of Mars, including its pressure and density characteristics. Precise tracking of the spacecraft will also improve our knowledge of Mars' ephemeris and body characteristics.

We are now currently developing the Mariner H and I spacecraft to orbit Mars in 1971, as illustrated in Figure 8. These two flights will actually accomplish two rather distinct missions. Mariner H is primarily a "mapping" mission. The spacecraft will be placed into a 60° inclined orbit with a 12-hour period which permits the maximum data return as the planet slowly rotates beneath each orbit. The spacecraft will systematically map the planet, returning maps of high resolution topography, surface temperatures, and atmospheric characteristics. Approximately 70 percent of the planet will be mapped in the first 90 days. We have high hopes that the spacecraft will actually last much longer than 90 days to study even more of the planet.

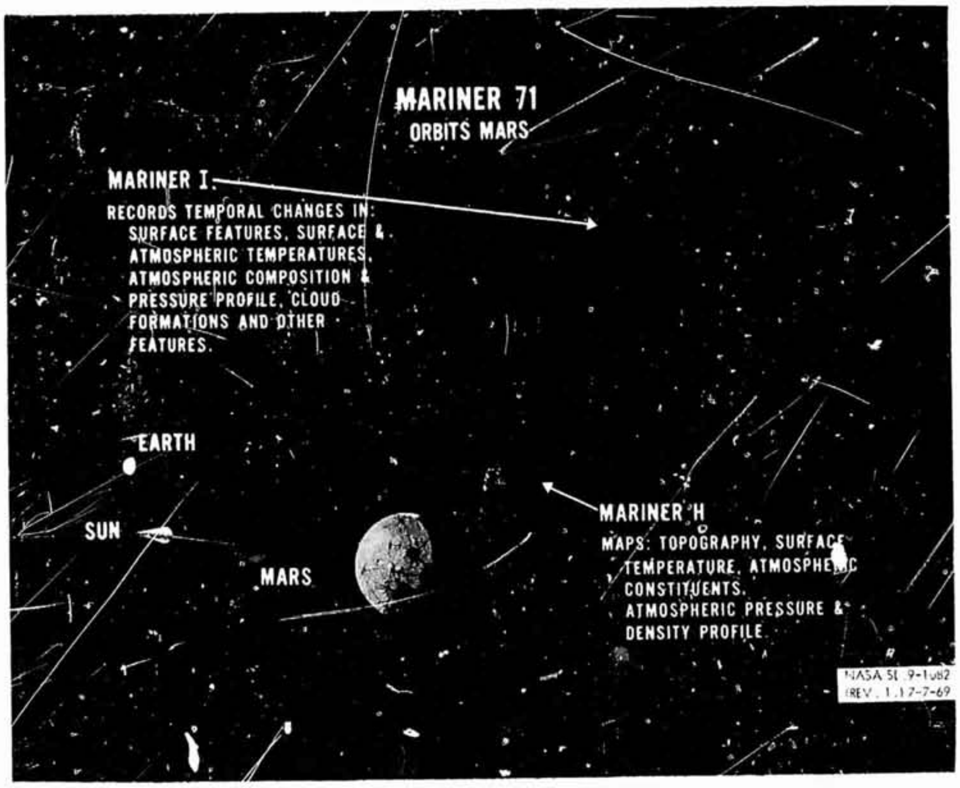


Fig. 8

Mariner I will concentrate on studying the various changes known to occur on Mars. For this mission it is desirable to get repeated viewing of the same points on the surface. Hence, Mariner I will be placed into a 4/3 synchronous orbit of 32-hour period which will return to view the same areas on the surface every three orbits (four Martian days). Mariner I will thus study phenomena such as the Wave of Darkening, the formation of the various colored hazes and clouds which have been observed on Mars, and hopefully the occurrence of the occasionally observed Martian dust storms.

In 1973, Viking will make our first landing on the surface of Mars, as illustrated in Figure 9. The Viking lander is a direct evolution from the Surveyor lunar landing vehicle, although Viking will be about twice the size of Surveyor. One of the reasons we can give Viking this enlarged capability is the help provided by the Martian atmosphere during the landing. You will recall that Surveyor had to depend entirely on rocket propulsion to slow down and land on the airless Moon. Viking, however, will fully utilize the Martian atmosphere first with aerodynamic braking of the vehicle within its aeroshell followed by further deceleration using a parachute. The lander depends on its throttled rocket propulsion subsystem only for the final touchdown maneuvers.

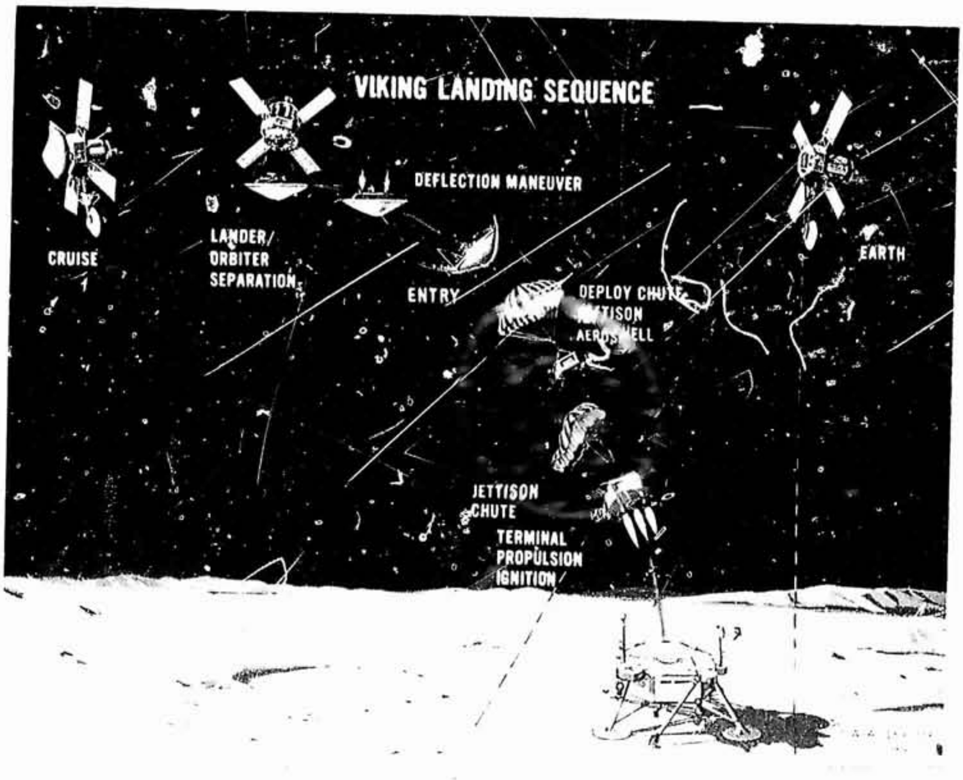


Fig. 9

The Viking will start its measurements of atmospheric characteristics during entry. Once on the surface (Figure 10) the Viking lander will deploy its camera and begin taking panoramic pictures of the surface, will erect its aeronomy package for making measurements of the local atmospheric pressure, temperature and wind conditions, and will scoop up a soil sample from the surrounding surface. The soil sample will be processed and sent to several instruments within the lander vehicle. One of these instruments will attempt to directly detect the existence of living organisms. However, it should be remembered that life forms on Mars may be quite different from those we are familiar with on Earth, and it is not at all certain that this life detection

ORBITER AND LANDER WORK AS A TEAM

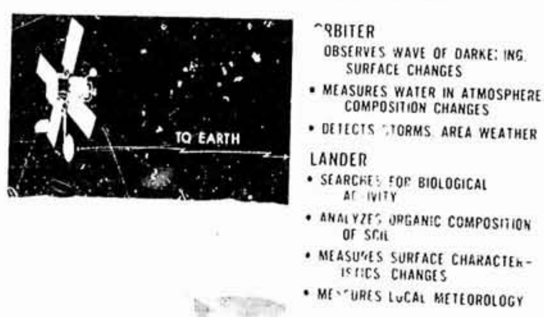


Fig. 10

instrument will give a positive measurement even if life should abound on the surface of Mars. Another set of instruments aboard the Viking, perhaps the most important of all, will accomplish a careful organic analysis of the soil sample. This analysis will then permit the design of much more specific life detection experiments which can be tailored to Martian conditions and organisms on any succeeding Mars landing mission.

It is important not to forget the Viking orbiter -- an important member of the orbiter/lander team. The orbiter complements the lander in a number of ways. First of all it serves as a communications relay station. The orbiter is much closer to the lander as it passes overhead than is Earth, so that data may be sent at a much higher rate to the orbiter. The orbiter can then relay the sorted data at leisure back to Earth. The use of this relay capability can more than double the amount of data returned from the Viking lander vehicle. In addition, measurements made from the orbiter will greatly help in the interpretation of the surface phenomena detected by the lander. For example, the orbiter will be able to watch for the Wave of Darkening as it passes the landed vehicle, and, should the lander detect a sudden increase in local wind velocity, the orbiter will be able to tell whether this is due to the approach of a large dust storm.

So far I have discussed only the Mars portion of our present program. However, we are also sending Pioneer-class spacecraft to other regions of the solar system, as indicated in Figure 11. I have already mentioned the space weather network of Pioneer spacecraft orbiting the Sun. In August of this year, we will launch the fifth in this series, Pioneer E, which will further improve this solar flare warning network. We are also sending Pioneer-type spacecraft both out from and in toward the Sun. In cooperation with West Germany, we will launch a spacecraft designated Helios which will pass in over 2/3 of the way from Earth toward the Sun, passing 10 million miles inside the orbit of the planet Mercury. Helios will be designed to withstand the considerable heating of this close pass to the Sun and will make many important solar measurements. The first of two Helios launches is scheduled for 1974.

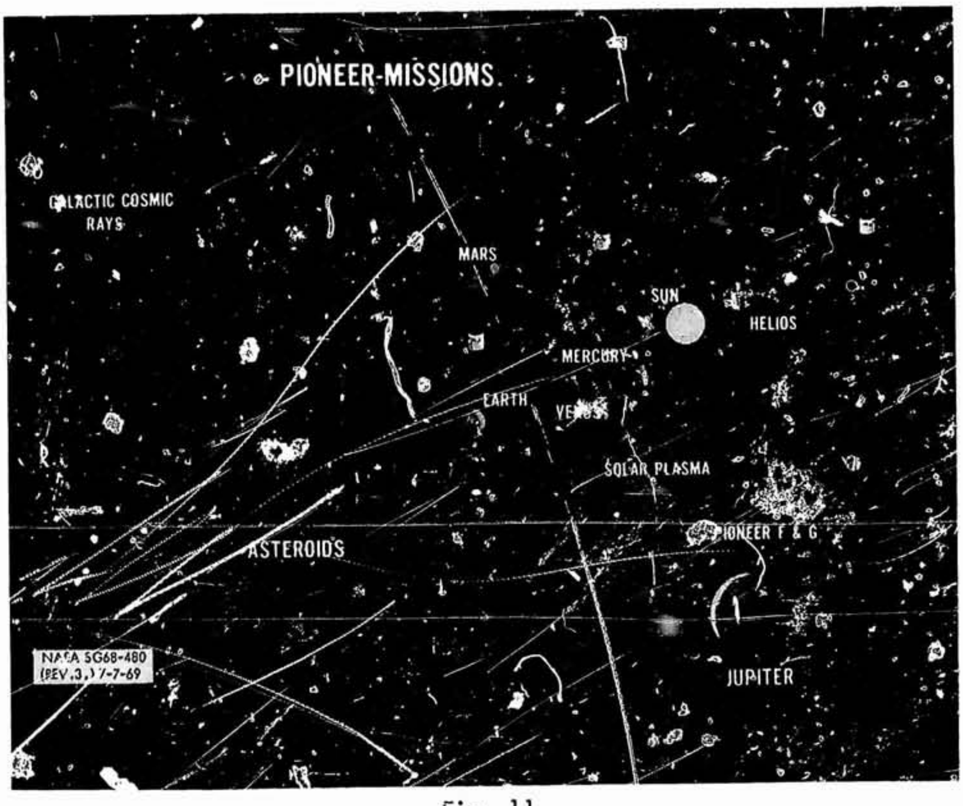


Fig. 11

We are also developing Pioneer spacecraft to pass far out from the Sun. In fact, the Pioneer F and G spacecraft will go five times farther out from the Sun than Earth's orbit to achieve a close flyby of the planet Jupiter. As shown in Figure 12, the Pioneer F and G spacecraft will pass out through the Asteroid Belt to make direct measurements at Jupiter itself, including accurate measurements of the suspected strong magnetic field and radiation belts. Now, this Pioneer spacecraft is a relatively small vehicle, carrying only about 1/3 the instrument payload of the Mariner spacecraft. However, even within this limited payload, we will be able to carry a spin-scan type camera which will take pictures of Jupiter at least four times better than the very best viewing we have ever had from Earth using telescopes. Another experiment will attempt to measure the very important helium/hydrogen ratio in the Jovian atmosphere.

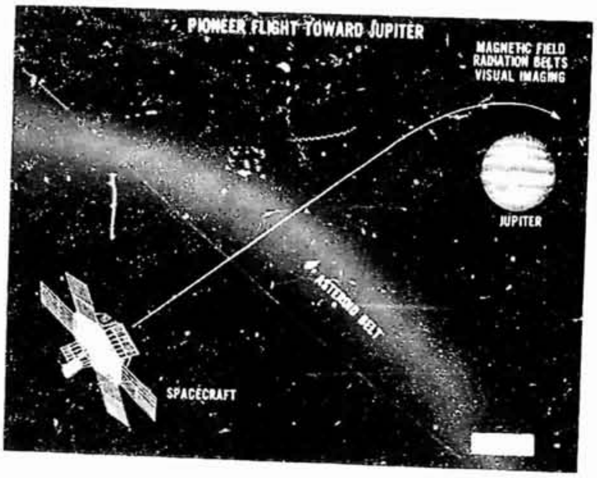


Fig. 12

Less spectacular than the Jupiter measurements but in many ways just as important will be the results of two experiments the Pioneer spacecraft will carry through the Asteroid Belt. These instruments will measure the distribution, size, and velocity of particles in the Belt. We currently think we can fly through this Asteroid Belt but we don't really know for sure. It is important to pin down the extent of this potential hazard in order to plan future flights not only to Jupiter but to all of the other outer planets as well. Thus, the planned launches of Pioneers F and G in 1972 and 1973 are coming none too early in our planetary exploration program.

Of the near planets, I have now described missions to Jupiter, Mars, and Venus, leaving Mercury as a notable omission. We are designing a mission to Mercury in 1973 to remedy that shortcoming. As shown in Figure 13 this will be our first two-planet mission, flying by Venus on its way to Mercury. One obvious reason for doing this is that we will receive data from two planets for the price of one launch. A second reason is that we can actually reach Mercury easier using the Venus swingby maneuver, reducing the required launch vehicle energy to less than half and permitting the flight of a Mariner spacecraft to Mercury using a modest launch vehicle such as the Atlas/Centaur. As the Mariner spacecraft flies by Venus, we will take our first closeup television pictures of this still puzzling planet. We don't really expect that there will by any large holes in the cloud layers over Venus that will permit us to view the surface, but if such holes exist we should see them in the 1973 flight. However, by viewing in the ultraviolet, we are quite certain that we will be able to view interesting structure in the upper cloud layers.

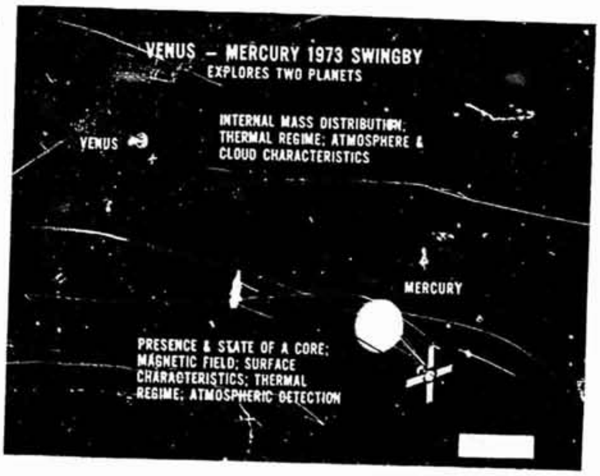


Fig. 13

2

The 1973 flight will make extensive measurements of Mercury during the close flyby maneuver. A magnetometer will attempt to detect the presence of a magnetic field at Mercury, which would in turn indicate the presence of a fluid core for that planet. Television cameras will view the surface in high resolution, looking at the entire lighted portion of the planet during the flyby. Other instruments will measure the thermal characteristics of Mercury and will search for the presence of an atmosphere. Results of the imaging and tracking data will also permit considerable improvements in our knowledge of the body characteristics of Mercury, such as its diameter and density.

I have now described all of the present ingredients of our FY 70 planetary flight program, and we can now return to our scorecard (Figure 14) to check our progress. As you can see, I have filled in our Mariner 71 orbiters and the Viking atmospheric entry and lander missions. I have also shown our flyby missions to Mercury and Jupiter. The program is now beginning to shape up into what we consider a highly desirable "balanced program." The forefront of progress in an ideal balanced program as shown includes second generation exploratory missions at the higher priority planets at the same time we are continuing to forge outward in the solar system with initial probing missions to the more distant planetary objects.

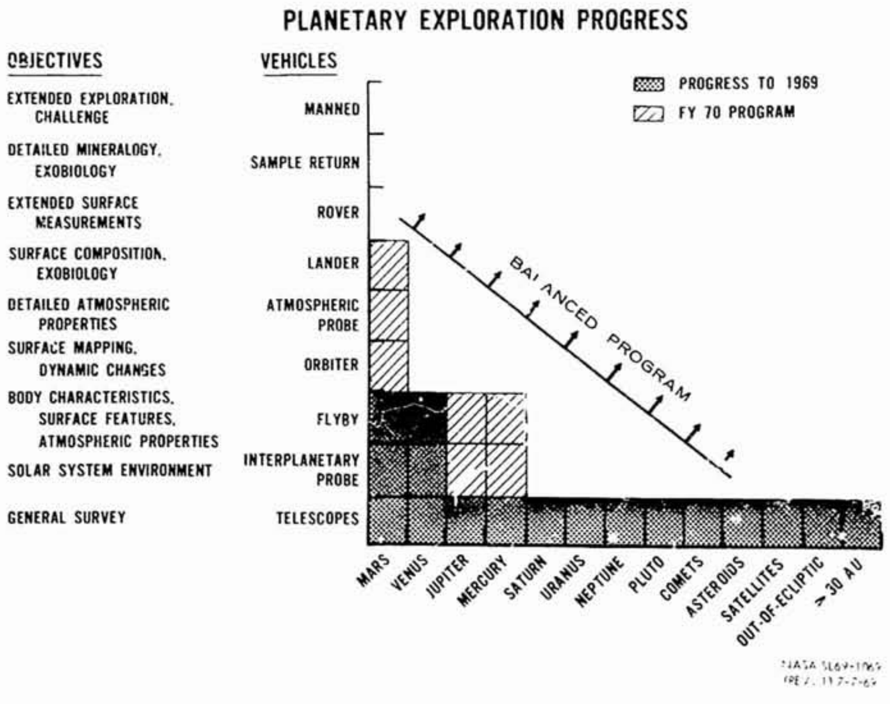


Fig. 14

Planned Future Missions

We have so far looked at past accomplishments and our present project endeavors. Let us now take a look at what lies ahead for the next few years.

I would like to start with a lesson we have leanred in studying our own planet Earth. As indicated in Figure 15 we have found it to be most efficient and economical to use two different classes of spacecraft in studying Earth. Relatively large high-powered orbiters such as the Orbiting Geophysical Observatories (OGO), Nimbus, and the Applications Technology Satellites (ATS) are necessary for making detailed studies of the surface and atmosphere of Earth. However, small spin-stabilized magnetically-clean Explorer orbiters have proved to be most economical for studying the solar environment surrounding Earth. It is these small Explorers that have largely mapped the bow wave and other interactions of the Earth with the solar wind.

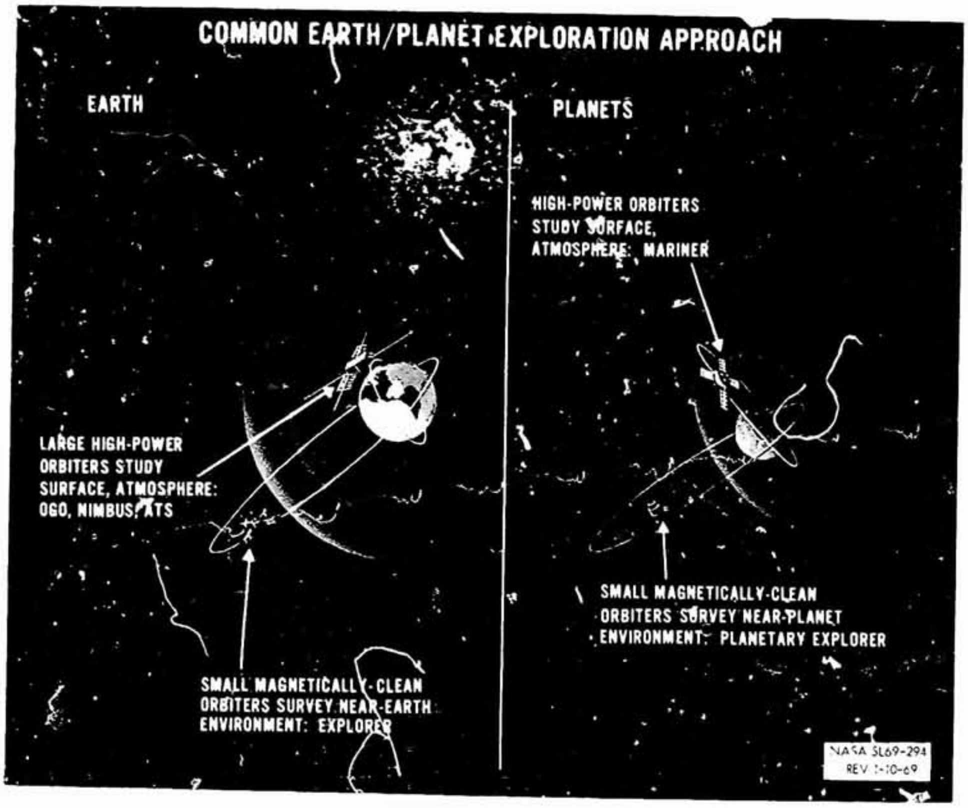


Fig. 15

We believe that we should take advantage of this lesson learned at Earth in our program to explore the near planets Mars and Venus. Here again we need relatively sophisticated spacecraft such as the Mariners to make the detailed studies of the planet itself. However, we can make better measurements of the solar environment about the planet at much lower cost using small Planetary Explorer orbiters. We are currently studying these missions in detail and are planning the first Planetary Explorer flight to Venus for 1973.

The Planetary Explorers can do a good job mapping the solar environment about Venus, but to study its atmosphere in detail we will need probes which actually penetrate the atmosphere. While valuable, the Russian Venera probes have returned only very sketchy atmospheric information. The Venus mission which our US scientists believe necessary to make a large advance in our knowledge of the Venusian atmosphere is illustrated in Figure 16. This mission features the deployment of multiple probes to enter various portions of the Venusian atmosphere at near simultaneous times. If you will recall the Venus atmospheric circulation theories presented by Dr. Rea, the points of critical activity are hypothesized to occur at the subsolar point directly facing the Sun, at the antisolar point directly opposite the Sun, and at the terminator interface between the irradiated sunlit side and the radiating dark side of the planet. Four probes entering at the subsolar, antisolar, terminator/equatorial, and terminator/polar regions will constitute a large step toward verifying these theories or advancing toward improved models of the Venusian atmosphere. Such a mission is being planned for launch in 1975.

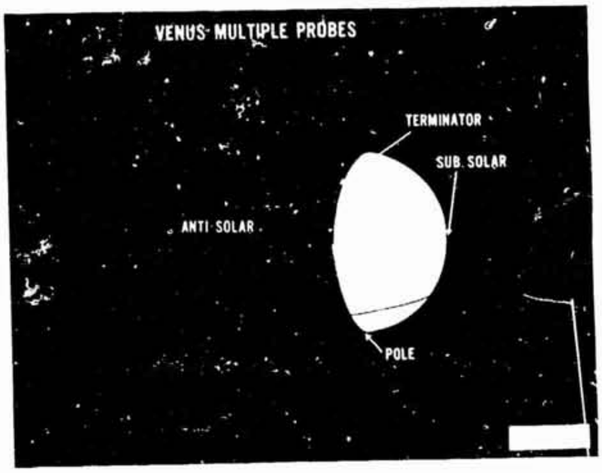


Fig. 16

Following the atmospheric profile measurements of the multiple probes, we will then want to directly study the interesting clouds and circulation patterns of Venus. One very promising mission proposed for accomplishing this is illustrated in Figure 17. In this buoyant station mission, we make use of a known characteristic of Venus -- its heavy CO_2 atmosphere -- to maintain our instruments where we wish them for long duration measurements. A relatively small 20-foot diameter balloon filled with hydrogen or helium will develop over 1-1/2 times as much lift in the Venusian atmosphere as it would in Earth's atmosphere, enabling it to support several hundred pounds of payload. The 250 miles per hour winds in the Venus atmosphere mentioned by Dr. Rea provide the motive force to carry the balloon about the planet. Precise tracking of the balloon will then permit direct measurements of the atmospheric circulation patterns. While circulating over the surface, small probes or drop sondes can be deployed from the balloon payload to provide profile measurements as desired through the atmosphere down to the surface.

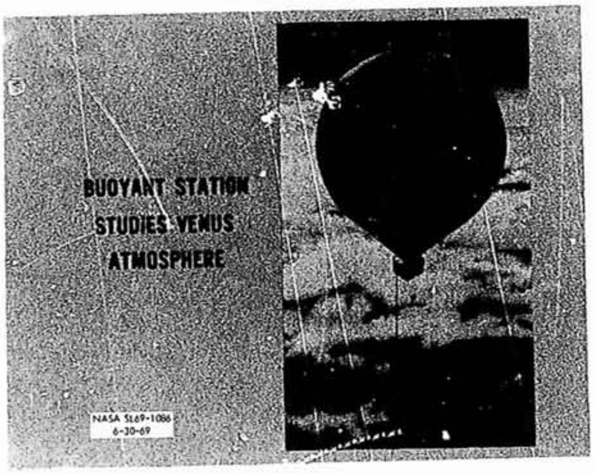


Fig. 17

The buoyant station is an example of utilizing a particular characteristic of the planet to enable us to accomplish our mission objectives. Another quite useful planetary property is its gravitational attraction, which can be utilized for a variety of swingby missions as illustrated in Figure 18. I have already discussed one such gravity assist swingby mission in the 1973 Venus-Mercury flight. However, the planet most useful for swingby flights is Jupiter with its huge mass of over 318 times the mass of Earth, or more than all the other planets combined. Jupiter attracts an approaching spacecraft like a tremendously powerful space magnet. If we fly over one of the poles of Jupiter, the spacecraft is deflected out-of-the-ecliptic plane and can pass out into an as yet unexplored region of space.

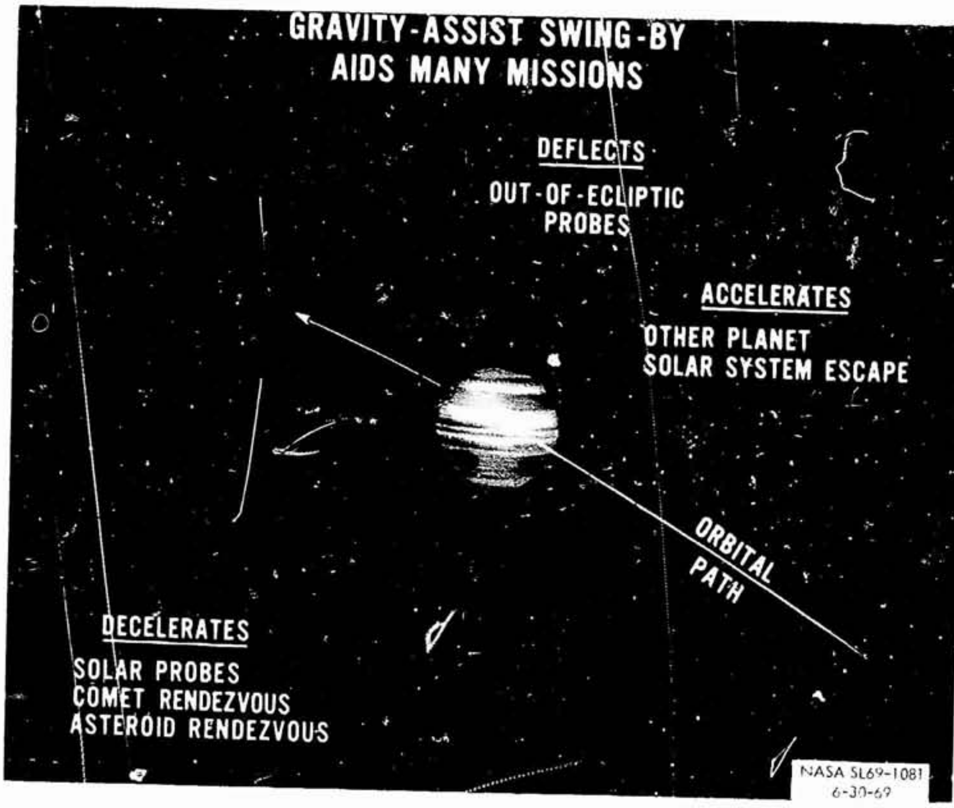


Fig. 18

This giant magnet of a planet Jupiter can also be used to accelerate or decelerate a passing spacecraft. Jupiter is not just sitting stationary in the solar system but is moving about the Sun at a velocity of approximately 25,000 miles per hour. If an approaching spacecraft passes in front of the planet, circling it in the direction opposite to Jupiter's motion, the spacecraft actually slows down in its path around the Sun. As the spacecraft departs Jupiter it begins to fall in toward the Sun, rapidly accelerating as it goes. This high velocity can be utilized for close solar probes or even solar impacts, as well as to rendezvous with fast moving objects in the solar system such as various comets and asteroids.

Perhaps the most useful Jupiter swingby maneuver is one in which the spacecraft passes behind the planet so that the attraction of Jupiter accelerates the spacecraft along its solar orbital path, performing a "crack the whip" acceleration which can boost the spacecraft by a large portion of Jupiter's 25,000 miles per hour velocity. This swingby acceleration is thus the equivalent of adding one or two extra stages to our launch vehicle and can permit faster flights to the far outer planets and even fast solar system escape missions.

Probably the most interesting and publicized of these Jupiter swingby missions is the "four-planet Grand Tour" illustrated in Figure 19. In the late 1970's, the outer planets are so aligned that a spacecraft can leave Earth to swingby Jupiter, then by Saturn, and on to Uranus and Neptune before escaping the solar system. This opportunity is very rare indeed, occuring only every 179 years or almost six generations. In one of the mysterious blessings of providence, this opportunity is presented to our generation at just the time when we will have the technical capability to take advantage of it.

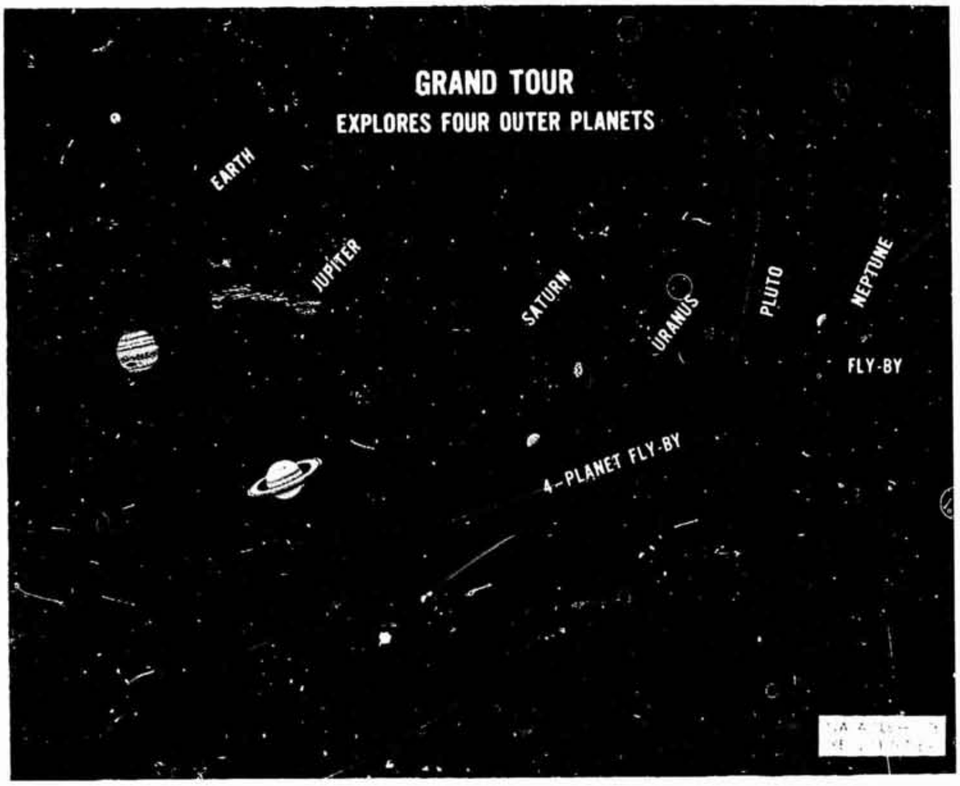


Fig. 19

Some of the benefits of the four-planet Grand Tour are obvious. For example, we can view four planets for the price of a single launch. However, it has one major disadvantage -- it is a relatively slow trip. Those beautiful rings of Saturn represent a potential hazard to the spacecraft and we dare not pass very close to them. Pessing farther from Saturn means that the spacecraft must travel slower in order to permit the gravity of Saturn to turn the spacecraft through the desired flight path angle. The slower velocity at Saturn also means a slower velocity at Jupiter, which in turn means a greater flyby distance at Jupiter also, so that we get a weakened swingby assist from both of these large planets. This necessity to avoid the rings of Saturn means that the trip time to Neptune will have to be at least 13 years long. Now, we currently have spacecraft in orbit about the Earth which are still operating fairly well after 6 years of lifetime, and there is also electronic equipment in undersea cables which is still operating after 13 years of service, so that I will not say that we could not accomplish a 13-year flight. However, I can say that it would certainly be a challenge.

Fortunately, we have found a solution to this potential problem. Using the same planetary alignment in the late 1970's, we can fly the two three-planet Grand Tours illustrated in Figure 20. In the first flight we swingby Jupiter, skip Saturn, and go directly to Uranus and then to Neptune. On a second Grand Tour we swingby Jupiter and then beneath the south pole of Saturn, avoiding the rings, then passing up out of the ecliptic plane to a close flyby of the planet Pluto. By avoiding the rings of Saturn, both of these three-planet Grand Tours can be relatively fast trips, reaching both Neptune and Pluto in approximately 7-1/2 years. Using these dual three-planet Grand Tours we can visit all five of the known outer planets. Needless to say, these Grand Tour prospects look most promising.

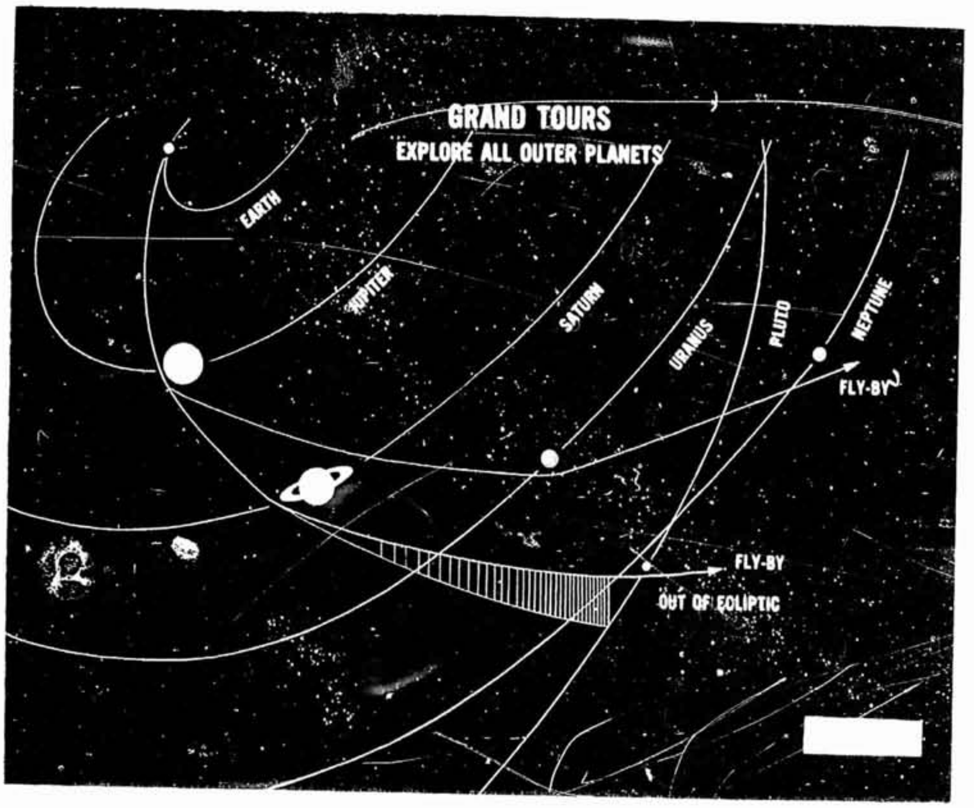


Fig. 20

The Grand Tours will require a new spacecraft design. The Mariner spacecraft is solar powered and generally limited to the regions of the near planets Mars, Venus, and Mercury. The Pioneer F and G spacecraft is designed for operation out to at least the orbit of the planet Jupiter, but it is a relatively small spacecraft which could neither carry the desired payload nor return the data from distances as far as Neptune and Pluto. The new Grand Tour spacecraft as currently conceived is illustrated in Figure 21. It weighs about 1500 pounds, or 1-1/2 times the weight of our most recent Mariner spacecraft. Possibly its most notable

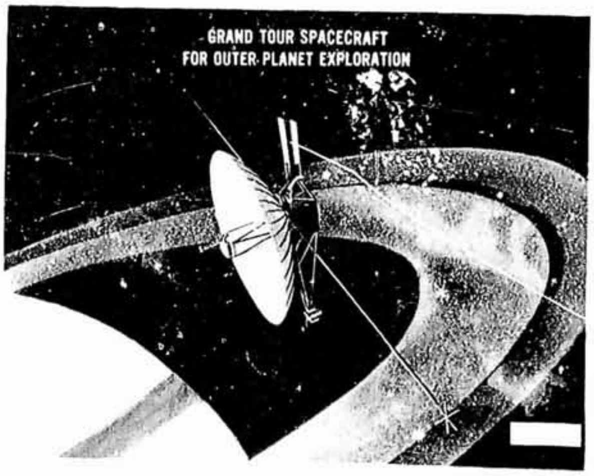


Fig. 21

feature is the large deployable antenna, approximately 15 feet in diameter. Remember that when we reach Neptune and Pluto we will be over 3 billion miles from Earth, presenting quite a challenge to the communications system. However, with the high gain antenna and other telemetry advances already demonstrated, this spacecraft will be able to return data from Neptune and Pluto faster and in greater total quantity than any of our earlier Mariner spacecraft were able to return from Mars and Venus.

Another notable feature of the spacecraft is its power supply of clustered Radioisotope Thermoelectric Generators (RTG). These RTGs utilize a nuclear energy source which provides the spacecraft with constant power, independent of its distance from the sun. Several RTGs have been flown in Earth orbit and have proved to be highly reliable long-life power supplies. Other unique features of the spacecraft are hidden within the black box portion, including a self-test and repair computer which has some of the characteristics of the computer Hal in the movie "2001--A Space Odessy," although hopefully this computer will not have the personality problems encountered with Hal.

Let us now return to the scorecard (Figure 22) to check the extent of our planning. I have now added onto this Figure those missions planned for the 1970's that I have just described. You will note that the Grand Tour missions, in addition to accomplishing flyby objectives at all of the outer planets, will make measurements well out of the ecliptic plane and in the regions of the solar system beyond the orbits of the planets Neptune and Pluto.

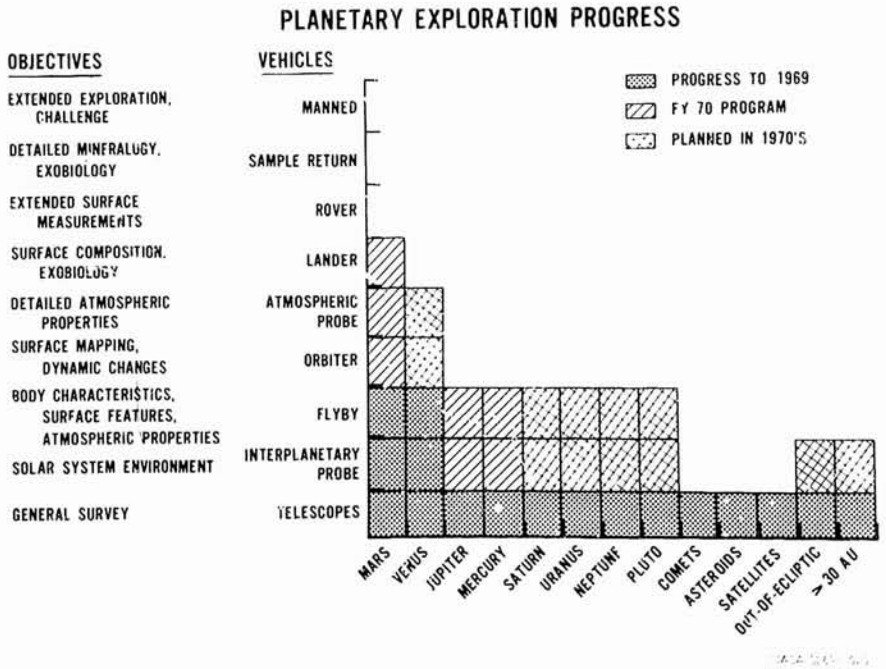


Fig. 22

It has not been possible in this limited discussion to describe for you all of the missions we are planning for the 1970's. However, I can quickly summarize them for you in my final scorecard (Figure 23). You can see that in addition to the missions described we are also planning surface roving missions to extend our measurement capability at Mars, additional orbiting and probe missions at the outer planets, and our first Mariner flights to representative comets and asteroids. As orbiters of the planets Jupiter and Saturn will make many flybys of the larger satellites of those planets, the Figure also notes reaching this stage in our planetary exploration program.

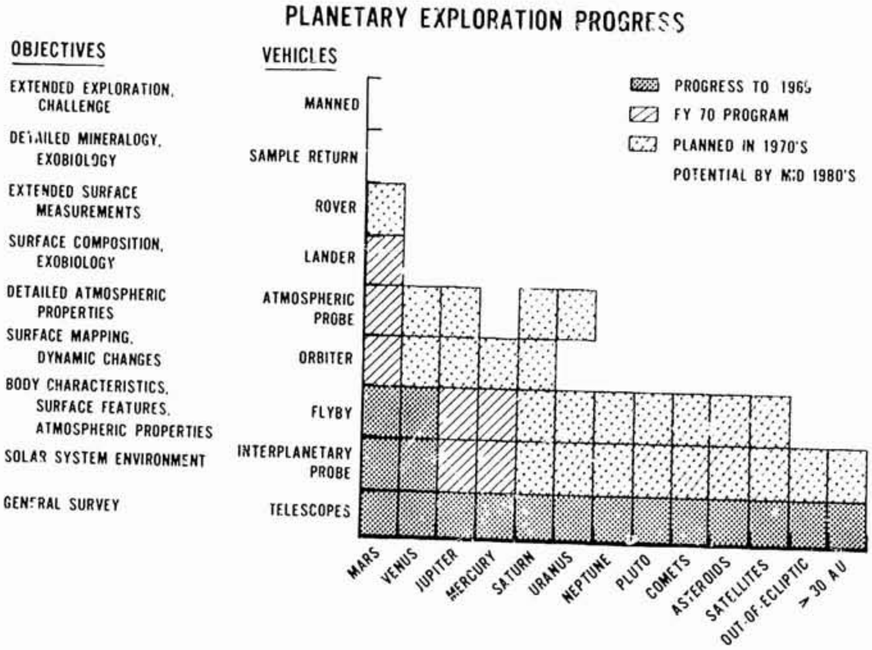


Fig. 23

Predicting for many years in advance the many factors affecting our space program, such as the Nation's economic status and the international situation, is extremely difficult. By 1980 our crystal ball has become hopelessly cloudy. However, I have indicated by the dotted line on this Figure missions that will be within our technical capability by the mid-1980's. Some of these missions are relatively easy to accomplish, such as landing on the asteroids. These asteroids are quite small so that the landing maneuver is more like a "docking" of two spacecraft. Landing on moons is more difficult, but it appears that an extension of our Viking lander technology will make landings quite possible on the larger satellites of the planets Jupiter and Saturn.

Perhaps the most interesting and technically challenging missions in the 1980's are being studied for the planet Mars. One is the Mars Surface Sample Return (MSSR) mission. While not an easy mission, it will be within our technical capability using a Saturn V/NERVA launch vehicle to send automated vehicles to return a surface sample from Mars back to Earth for detailed analysis in our well-equipped Earth laboratories. Also, I would be completely remiss not to make some mention of the mission to land a manned crew on the surface of Mars and return them to Earth, much as Apollo is about to do on the Moon. I think that we all know that this mission will be flown some day and it is just a question of how soon. What I can say with confidence is that we can be technically capable of performing this mission in the early to mid 1980's.

That concludes a summary of the spacecraft portion of our planetary exploration program. As a footnote I would like to comment that we in the Planetary Programs Office cannot help but get quite enthused as we view our capabilities and prospects for the decade ahead. During the 1970's we can send spacecraft to visit all the major objects in the solar system and can unlock for mankind many of the long-withheld secrets of our solar system. In doing this, we are confident that we will also greatly increase our understanding of our home planet Earth.

I would now like to return the podium to Don Hearth for some concluding remarks.

SUMMARY

By: Mr. Donald P. Hearth

We'll now refer to Mr. Kraemer's last chart (Figure 23) to summarize the point that I made at the beginning; the Planetary Program is balanced.

Balance means a mix of the earth-based observations reviewed by Dr. Brunk with the space flight observations reviewed by Mr. Kraemer.

Balance also means that while we may be putting more stress on Mars at the present time, it's not being done at the expense of broad-based exploration. Note that the on-going program includes missions into Mercury and out to Jupiter. This is required to make the comparative studies that Dr. Rea pointed out as so important. Balance also means a mix of the small spacecraft of the Pioneer type, with the larger Mariner and Viking type.

I'd like to come back from the future now--back from the suggestions of 10 or 15 years from now--to this year. What are we doing now? What can we expect in the remainder of this year?

We have one more launch to be made this year--that is the last of the current Pioneer series (Figure 1).

This will be the fifth in a series of spacecraft that will be orbiting the Sun. The Pioneer E spacecraft will be put into a trajectory around the sun that will keep it very close to the earth for some 900 days, thus forming a very good network around the solar system (Figure 2).

PIONEER MATED TO DELTA READY FOR LAUNCH

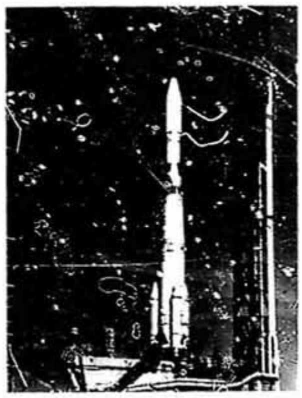


Fig. 1

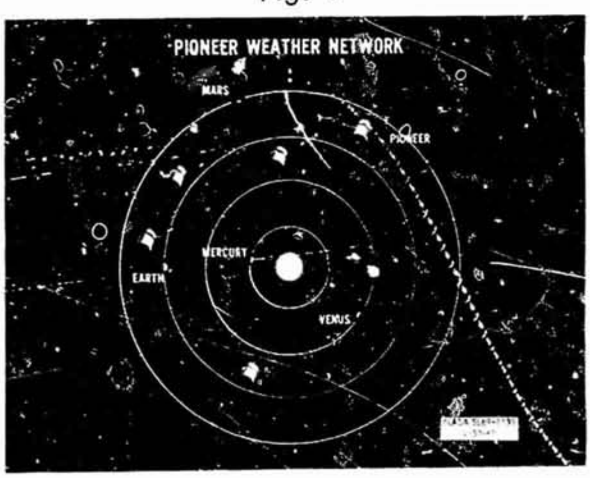


Fig. 2

Perhaps the biggest event of this year for us, though, is coming up in less than 3 weeks.

That's when the Mariner VI and VII spacecraft will fly by Mars(Figure 3). Mariner VI was launched in February followed about a month later by the launch of Mariner VII. Mariner VI will make it's closest approach early in the morning of 31 July, Eastern time. Mariner VII will follow almost exactly 5 days later.

We are doing something different with these two spacecraft from that done with Mariner IV. We will be looking at the planet as we approach it (Figure 4), starting 2 to 3 days before closest approach.

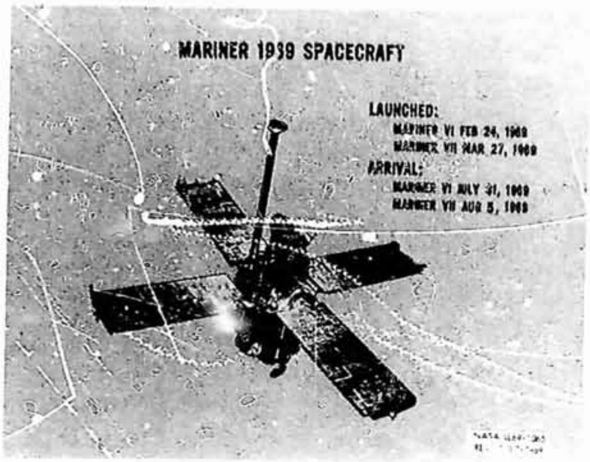


Fig. 3

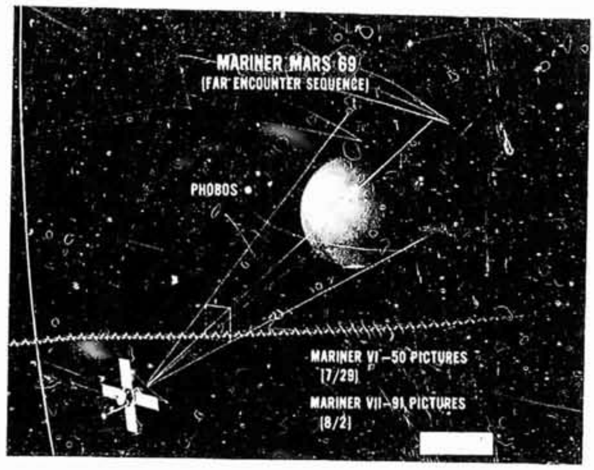


Fig. 4

In the case of Mariner VI, 2 days before the Mariner's closest approach, we will begin to take television pictures of the planet; taking a total of some 50 pictures in this way. These will be transmitted back to earth over the high-rate 16,000 bits per second communication system. Transmission will start about 9:30 Eastern time on the night of 29 July.

Four days later--Mariner VI will begin the same process. With the two spacecraft we will get some 140 pictures as we approach the planet--perhaps for the first time giving us a better feel for some of Mars' dynamic behavior.

Figure 5 is a sample of the 50 far encounter pictures to be obtained by Mariner VI. The first one to be transmitted will be at a distance of some 770,000 miles from the planet at a resolution similar to what we can get with our best earth-based telescope. As the spacecraft approaches the planet, the view of the planet becomes larger. We'll be looking at different portions of the planet, until finally, the last far encounter picture from Mariner VI will be from a distance of about 110,000 miles at a resolution of about 5 times better than the first of these pictures. The spacecraft will still be about 100,000 miles from the planet at that time.

During the near encounter, though, the spacecraft will come in very close, flying by the planet at about 2000 miles. Mariner VI will view the equatorial region--looking at the more temperate portion of the planet. The photographic resolution will be on the order of about 300 meters. You'll be able to pick out an object about the size of the Rayburn Office Building, as an example.

Mariner VI, which will fly by Mars almost exactly 5 days later, will view the southern hemisphere and by slewing the scan platform will view the edge of the southern polar cap. From this observation, perhaps we'll get a better idea of what the southern polar cap is made of--carbon dioxide or water or some mixture.

This concludes our report to you today. We have enjoyed having the opportunity to talk about the program that we're very proud to be associated with. We think it's one of the most exciting and most rewarding parts of the NASA program.

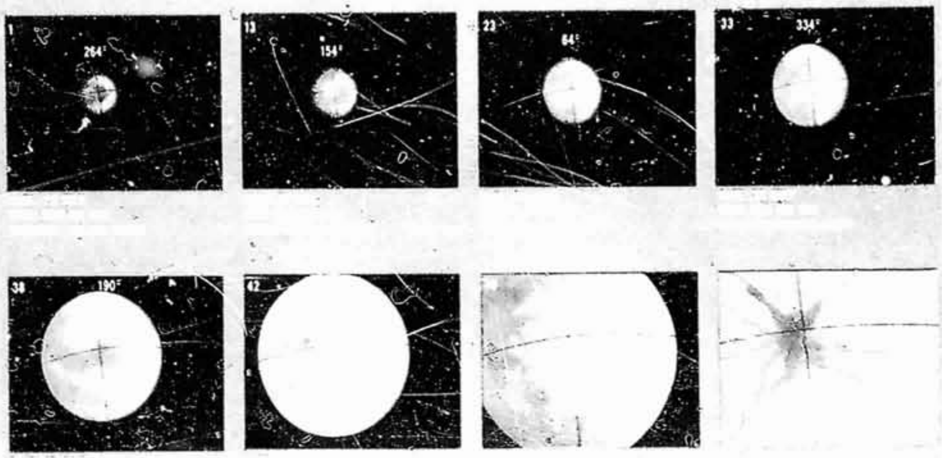

1
264°
13
154°
23
64°
33
334°
38
190°
42

Fig. 5

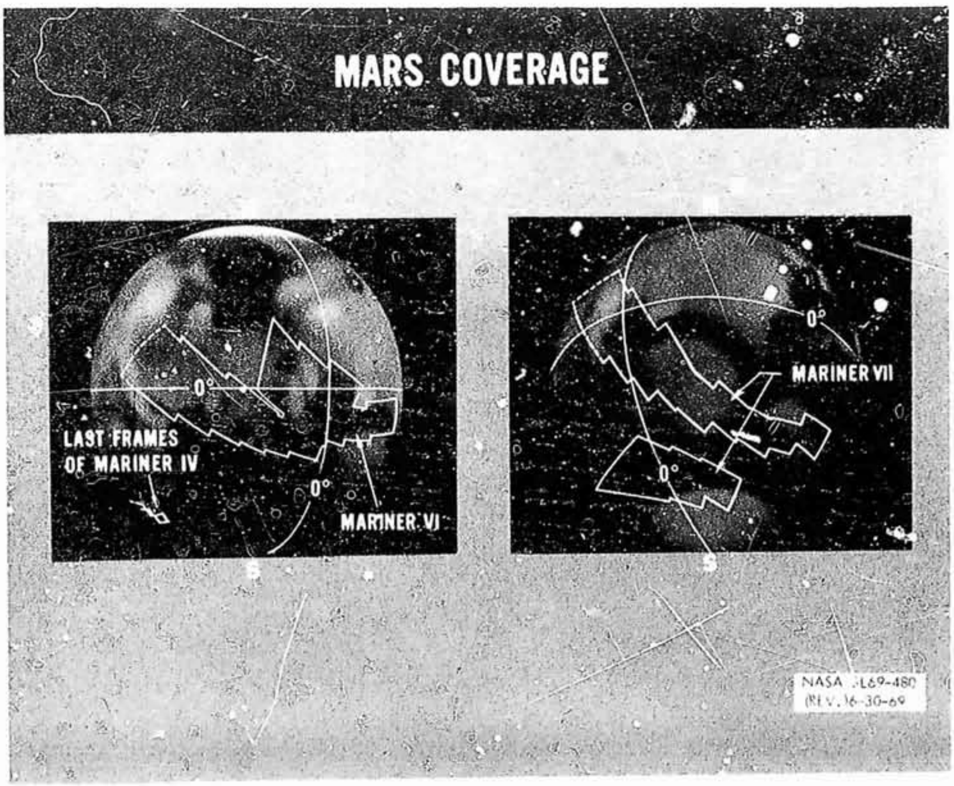

MARS COVERAGE
0°
LAST FRAMES
OF MARINER IV
0°
MARINER VI
0°
MARINER VII
0°

Fig. 6

ADDENDUM

A significant portion of this presentation referred, in future tense, to the Mariner VI and VII encounters and the launch of Pioneer E. Therefore, later information on these missions, available at the time of publication, is included here. Preliminary analyses of data from the highly successful Mariner VI and VII encounters are summarized below. Launch of the Pioneer E mission was attempted on 27 August 1969 but orbit was not achieved due to launch vehicle booster failure.

SUMMARY OF MARINER '69 MISSION RESULTS

Preliminary analyses of the Mariner Mars '69 Program scientific data indicate the following:

The Martian surface has numerous craters -- many from 30 to 50 miles in diameter and some with diameters as large as 300 miles. The sharp demarcation of the light and dark areas as observed from Earth were shown to be more diffused and splotchy when observed in higher resolution. The polar cap region, also heavily cratered, has a jagged edge and appears to be covered by a thick layer of ice. It is believed that the ice is carbon dioxide, with a small admixture of water.

The appearance of the Martian surface indicates there are surface modification processes different from the Moon. The unique absence of craters in the bright Martian "desert," Hellas, distinctively differentiates Mars from the Moon and strongly indicates an activity in that region which obliterates the craters.

The surface temperature was found to be relatively moderate with an indicated day-time temperature of -63°F to 62°F and night-time temperature of -63°F to -153°F. The southern polar cap temperature was measured by the infrared radiometer as -189°F which corresponds to the temperature at which solid CO_2 is in equilibrium with the Martian partial pressure of CO_2. The infrared spectrometer measurements were not in agreement with the radiometer readings and indicated a polar cap temperature of about -94°F. However, these latter measurements were made over a larger integrated area than the radiometer's measurements and may consequently reflect the average temperature of bare ground and frozen CO_2 covered regions.

Consistent with previous observations, Mars' surface pressures were observed to lie between .0035 and .0065 Earth atmospheres. The lower pressures indicate high ground elevations -- an area at 0.0035 atmospheres being about 6 km higher than one at 0.0065 atmospheres. Atmospheric temperatures at the surface varied from 12°F in the equatorial region to lows of -153°F to -189°F in the southern polar region. Evening ionospheric observations indicated electron densities of the order of 1.5×10^5 electrons per cubic centimeter at altitudes of 130 km. This is comparable to the Earth's ionospheric electron density. Spectroscopic measurements of the atmosphere confirmed the presence of carbon dioxide, carbon monoxide, and water vapor. There is a tentative indication that the lower atmosphere may contain water ice. Nitrogen and ozone were not detected above instrument limits. The controversial blue haze, observed by Earth-based telescopes, also was not detected.

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